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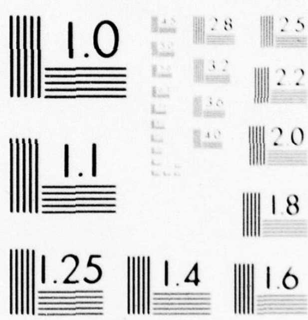

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REPORT NO. FAA-EM-78-4

IMPACT OF FAA E & D ELEMENTS — EIGHT AIRPORT SUMMARY -

JANUARY 1978

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U.S. DEPARTMENT OF TRANSPORTATION
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16. Abstract

The potential benefits of implementing the products of selected FAA Engineering and Development Programs at eight major airports are surveyed. Best estimates of the expected performance of the Vortex Advisory/Wake Vortex Avoidance Systems (VAS/WVAS), Metering and Spacing (M&S--part of the ATC System Automation program) and the Discrete Address Beacon System are used as basis for estimating the increase in airport capacity that might be realized from the collective use of those systems in a pre-1985 case and a post-1985 case. Best estimates of the expected performance of the Airport Surface Traffic Control (ASTC) system, the Microwave Landing System (MLS), and Area Navigation Equipment (RNAV) plus results of recent FAA/TSC studies are used as the basis for estimating the individual impacts of those systems on controller workload, changes in air routes to reduce time and fuel, and ILS interference problems at the eight airports. This report summarizes the potential benefits.

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Many persons and organizations contributed to the process leading to the evaluation of benefits at the eight airports. The FAA/TSC program office personnel for the various E&D elements provided the basic program descriptions and performance capabilities.

The details of the operation at the airports drew upon the work done by the Airport Improvement Task Forces and FAA contractor, Peat, Marwick, Mitchell & Co. (PMM).

The details of capacity model input specifications and data were coordinated with the Airport Improvement Task Forces and the Office of Systems Engineering Management (OSEM). The airport capacity values used for evaluating the E&D elements were generated by the PMM/FAA capacity model, based on the inputs specified by MITRE METREK. Model runs were made by PMM or the AEM-100 Division of OSEM.

The evaluation of the impacts of ASTC, RNAV and MLS was based on previous reports, with airport specific additions as appropriate. On-site evaluation of MLS benefits was made jointly by members of the FAA's MLS program office and METREK. TSC provided a draft ASTC evaluation based on site specific analyses.

The details of the analysis for each of the eight airports are given in MITRE Technical Report MTR-7350:

Vol. I	Chicago O'Hare	December 1976
Vol. II	New York (JFK and LGA)	April 1977
Vol. III	Denver	July 1977
Vol. IV	Atlanta	August 1977
Vol. V	Los Angeles	August 1977
Vol. VI	Miami	September 1977
Vol. VII	San Francisco	September 1977

The following METREK staff members contributed significantly to one or more of these studies: A. L. Avant, Dr. A. L. Haines, Dr. R. R. Iyer, Dr. A. N. Sinha and W. J. Swedish.

EXECUTIVE SUMMARY

This report summarizes an evaluation of the potential benefits of implementing the products of selected FAA Engineering and Development (E&D) programs at eight major airports that have been subjects of special Task Force efforts.

The following E&D elements were included in the analyses:

- Wake Vortex Advisory/Avoidance System (VAS/WVAS)
- ATC System Automation, including Metering and Spacing (M&S)
- Discrete Address Beacon System (DABS)
- Airport Surface Traffic Control (ASTC), including improved Airport Surface Detection Equipment (ASDE-3) and Tower Automated Ground Surveillance (TAGS)
- Area Navigation (RNAV)
- Microwave Landing Systems (MLS)

APPROACH TO EVALUATION OF E&D IMPACTS

The evaluation of the impacts of the E&D elements at the eight airports was divided into two parts. One part consisted of the evaluation of the impacts of ASTC, RNAV, and MLS. These impacts were developed, for the most part, from previous studies by several organizations as to the expected benefits of each of these elements. The studies were augmented as necessary by new site specific analyses.

The other part consisted of the evaluation of the impacts of WVAS, ATC System Automation and DABS on airport capacity. For this purpose several likely future ATC environments were defined. These environments reflect implementation of E&D elements in the order in which they might be realized in the operational system.

1. In the near term, the Vortex Advisory System (VAS) and Basic Metering and Spacing are expected to improve M&S delivery accuracy and permit reductions in the 4, 5 and 6 nmi IFR wake vortex separations when VAS observations of meteorological conditions indicate it is safe to do so, while maintaining the current 3 nmi minimum IFR separation standard for aircraft pairs not impacted by wake vortex.

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2. In the intermediate term, Basic Metering and Spacing is expected to be supplemented by the Wake Vortex Avoidance System and some improved surveillance capabilities for the controller (e.g., digitized display of separation measures, computer generated alarms). In this analysis, the basic IFR arrival separation standard is reduced to 2.5 nmi for those aircraft pairs currently governed by a 3 nmi separation standard. Other aircraft pairs, separated by more than 3 nmi today because of wake vortex hazard, are assumed to have significantly reduced separation requirements as well, but to a level above 2.5 nmi. Reduced departure separation requirements are also assumed.

3. In the far term, it is anticipated that the Metering and Spacing system will evolve to an improved capability, and the Discrete Address Beacon System will be introduced. The basic IFR arrival separation standard is assumed to be reduced to as low as 2 nmi for the least vortex impacted aircraft pairs (e.g., large aircraft following small aircraft). For other aircraft pairs, spacings are also further reduced in this analysis, but remain at values larger than 2 nmi. Departure separations are assumed to all be reduced to 60 seconds. Obviously, this far term capability requires extensive E&D effort to arrive at an implementable state.

Comparable inputs were also developed to reflect the application of E&D elements in VFR conditions for the near, intermediate and far term.

IMPACT OF VORTEX SYSTEMS, ATC SYSTEM AUTOMATION AND DABS

The impact of WVAS, ATC System Automation, and DABS through reduced spacings on airport capacity is summarized in Table 1. The percentage capacity gains shown in the Table compare the specified future ATC environment, with and without E&D systems implemented.

The ranges of capacity gains result from the wide variety of airport specific runway configurations and other operating conditions. Largest VFR gains are for ORD and JFK which have efficient parallel or intersecting runways. Gains of the order of 20-25% could occur by the far term and could provide significant relief at these airports. Smallest VFR gains are for MIA, LGA and SFO which are limited by the inefficiencies of intersecting runways or single runway mixed operations. Gains in these conditions are less than 10%.

Under IFR conditions the largest capacity gains are for LAX, JFK, ORD and SFO. These airports can conduct IFR operations with dual lanes or efficient intersecting configurations. Gains of 34-51% in

TABLE 1
SUMMARY OF IMPACT OF E&D ELEMENTS ON AIRPORT CAPACITY AT THE EIGHT AIRPORTS*

		NEAR TERM	INTERMEDIATE TERM	FAR TERM
		VAS + BASIC M&S	WVAS + BASIC M&S + IMPROVED SURVEILLANCE CAPABILITY	WVAS + IMPROVED M&S + DABS
		CAPACITY IMPROVEMENT (PERCENT)*		
VFR	NO VORTEX HAZARD	2-10%	5-15%	9-21%
	VORTEX HAZARD	0-4%	2-10%	4-12%
IFR	NO VORTEX HAZARD	0-15%	4-31%	5-51%
	VORTEX HAZARD	0-4%	1-15%	2-27%

"NO VORTEX HAZARD": VAS/WVAS MINIMUM SEPARATIONS ACCEPTABLE

"VORTEX HAZARD": HAZARD OBSERVED FOR VAS/WVAS MINIMUM SEPARATIONS; INCREASED SEPARATIONS REQUIRED

*COMPARISON OF FUTURE ENVIRONMENT WITH VERSUS OPERATIONS WITHOUT E&D IMPLEMENTATION

the far term for these airports would provide significant relief from present and future IFR capacity limitations and resulting congestion. Even in the intermediate term, substantive gains of 13-31% are achievable. Smallest IFR gains are for MIA which has mixed operations on a single runway and for LGA when operating as a single runway. The gains, even in the far term, are 5% or less in such configurations.

Under the increased spacings that must be used when VAS/WVAS indicates a vortex hazard may be present, capacity gains are significantly less. Typically, the gains are about half of those seen when VAS/WVAS indicates the full limit of reduced spacings may be employed.

The single most critical determinant in the level of capacity benefit is the runway use configuration, noted in the discussion above. The second major determinant is arrival runway occupancy time. If currently observed runway occupancy times hold in the future (as assumed by Task Forces), they will determine the minimum interarrival spacing on many runways. Some airport specific improvements, as well as emphasis on pilot motivation and techniques, are likely to achieve decreases in runway occupancy times not accounted for in Table 1, and thus could result in further capacity gains.

IMPACTS OF ASTC, RNAV, AND MLS

Impacts of ASTC, RNAV and MLS were evaluated on an airport specific basis, drawing upon previous studies and analyses, as well as on-site visits.

For two airports currently without ASDE (DEN, LGA) there are significant benefits to providing airport ground surveillance via ASDE-3. At LGA, ASDE will help the local controller to increase capacity and reduce workload at those times when runway intersections or exits are not visible to the controller. At DEN, similar benefits are possible when the controller is working with the long sighting distances (up to 3 miles) to the far ends of the north/south runways. For both DEN and LGA there is a needed improvement of 30% in ground controller capability versus position reports.

ASDE-2, where deployed, provides significant benefits. However, the reliability, maintainability and display improvements represented by ASDE-3 are necessary to insure that an ASDE is usable when it is needed. The availability of any ASDE results in a ground controller capability increase (up to 30%) above that of position reports at ORD, JFK, ATL and SFO. Ground and local controller workload reductions are experienced at JFK when arrivals must cross an active departure runway. There are also significant local and ground control runway capacity benefits at ATL where arrivals must taxi across one or two active runways.

TAGS will enable the ground controller to work as effectively during periods of low visibility as he does today during VFR conditions. This will be a necessary improvement at those airports needing a capability, during low visibility conditions, above 60 operations/hour (one ground controller) or 85 operations/hour (two ground controllers). Conservative traffic projections and TAGS establishment criteria presently indicate such a need at O'Hare, Atlanta, Los Angeles, and possibly Denver.

Simulation studies at JFK have indicated 2D or 3D RNAV will permit reductions in controller workload, both in the number of control instructions (up to 54% reduction) and in radio talk time (up to 42% reduction). These studies indicated that substantial reduction in controller workload will be possible even when only part of the aircraft fleet is RNAV equipped. The magnitude of the workload benefit is highly sensitive to the detailed design of the RNAV route structure, requiring specialized route designs to allow the controller to employ RNAV effectively. These designs do not significantly reduce route lengths or times for either RNAV or conventionally equipped aircraft but rather allow for better control and reduced communications between pilots and controllers. These workload benefits were not directly translatable in the simulations to airport capacity increases.

The more sophisticated 3D RNAV, if fully implemented, may also provide for more fuel and time efficient utilization of the terminal airspace. The potential for shorter route lengths in an RNAV route structure environment could possibly yield fuel and time savings of up to $17.1M annually at JFK. These savings are maximum estimates predicted on full employment of an optimized RNAV/M&S route structure. Even with 100% 3D RNAV equippage, the per aircraft savings are small ($10-20 per jet transport aircraft operation), which by itself may fail to provide sufficient justification for investment in expensive airborne equipment. In mixed (i.e., less than 100% equipped) RNAV environments there appears to be a sharp tradeoff between route length savings and controller workload benefits, at least in the New York metroplex environment. The tradeoff severely limits the realizable user dollar benefits for RNAV in the terminal area in the near or intermediate terms.

MLS provides for a range of benefits. The most significant is the ability of MLS to provide for precision curved approach/departure paths. This may result in:

- reduced airspace conflicts between LGA and JFK, leading to reductions in annual noise exposure at both airports, and a 3% average annual capacity increase in LGA (with higher percentage values of potential delay reduction)

- reduced departure airspace and noise problems at SFO (Runways 28L and 28R)
- reduced arrival noise at SFO (Runways 28L and 28R), and to lesser extent, ATL
- extended use of efficient VFR procedures to lower minima at JFK (including Canarsie) and ATL.

These capabilities are of significant assistance to noise or capacity limited airports.

Other useful MLS benefits at specific airports are:

- availability of new instrument landing frequencies in LAX, SFO regions (where none are now available within present VHF ILS channels, and significant future needs are projected)
- reduced ILS glide slope critical areas at LGA, leading to 9 operations/hour capacity recovery when on single runway 13 operations.

MLS may also provide benefits to several of the eight airports in reduced localizer interference, ease of siting, and operational efficiency.

CONCLUSIONS

1. There is a major capacity benefit at most (but not all) of the eight airports, made possible largely with the implementation of WVAS and M&S systems. The IFR benefit of the packages of E&D improvements for efficient runway configurations, when compared to the future environment with no E&D implementation, ranges up to 15% in the near term (3 nmi minimum standard), 30% in the intermediate term (2.5 nmi minimum standard), and 50% in the far term (2 nmi minimum standard). A 2 nmi minimum IFR separation represents a significant E&D effort. The comparable benefits of M&S and vortex systems under VFR conditions are 10% (near term), 15% (intermediate term) and 20% (far term). These are significant benefits for the heavily congested airports examined in the Task Force work.

   The single most critical determinant in the level of capacity benefit is the runway use configuration. Independent runways, dual-lanes and efficient intersecting runways offer the greatest benefit. The second major determinant is arrival runway occupancy

time. Currently observed runway occupancy times, continued into the intermediate and far term, determine the minimum interarrival spacing on many runways.

2. There is a continuing need for reliable ASDE at seven of eight airports. For five of these seven airports, ASDE-3 would provide reliability, maintainability and display improvements over the existing ASDE-2 and thus allow significantly enhanced operating efficiency (compared to ASDE-2). For two of these seven airports not presently ASDE equipped, the availability of a new ASDE-3 offers a needed enhancement to IFR capabilities. TAGS will provide a ground controller capability which will not degrade as weather worsens. This will be needed at three of the eight airports where low visibility demand will exceed present capability.

3. RNAV, if widely implemented, could provide for significant controller workload reductions. With an RNAV optimized route structure, time and fuel savings from reduced route lengths might accrue (as much as $17.1M annually for JFK in a fully implemented 3D RNAV/M&S environment). These total savings are, however, based on small per aircraft savings and might not in themselves justify investment in expensive airborne equipment. The savings are highly sensitive to both the detailed structure of the RNAV routes and the ability of the controller and/or M&S to effectively employ the optimized route geometries.

4. MLS could provide significant airport specific benefits, particularly in the areas of:

   - reduced noise and airspace conflicts largely arising from the curved approach capabilities of MLS

   - reduced glide slope critical areas/ILS interference.

   In addition, in the regions surrounding three of the airports, there is a need for the additional landing system channels available with MLS.

The FAA is embarking on a program to do computer simulation modeling at these eight, plus other, airports. This program will give a more detailed understanding of the relationship of capacity to delay. It will permit quantification of the potential benefits of E&D products in terms of dollar savings in reduced delay.

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1. INTRODUCTION

1.1 Background

In 1974, the FAA decided to sponsor a series of Airport Improvement Case Studies, at eight airports, to investigate what actions could be undertaken to plan implementation of a number of suggested airport improvements. These studies were to include actions that could be taken in the immediate future to improve capacity and reduce delays and an examination of the potential benefits of longer term improvements, including the installation and use of the products of current FAA Engineering and Development (E&D) programs. Seven Task Forces, with representatives of the Federal Aviation Administration (Headquarters and Regional), the Air Transport Association of America (ATA), airlines, and airport operators, were formed to conduct the studies (one Task Force dealt with both JFK and LGA). The MITRE Corporation (METREK Division) and Peat, Marwick, Mitchell and Company provided support to the FAA's Office of System Engineering Management (OSEM). MITRE METREK was tasked by the FAA's Office of System Engineering Management to provide a separate report to each of the Task Forces on the potential benefits of implementing the products of selected FAA E&D programs (called E&D elements for convenience throughout the report) at the airport of concern.

1.2 Purpose

The purpose of this report is to provide a summary of the potential benefits of E&D elements at each of the eight airports. The seven Task Forces considered the following eight airports: Chicago O'Hare, New York JFK, New York LGA, Denver Stapleton, Atlanta Hartsfield, Los Angeles International, Miami International, and San Francisco International.

1.3 Scope

The analysis of the potential benefits of the FAA's E&D programs on operations at each of the eight airports was limited to the six E&D programs expected to have the most effect on terminal area and airport operations. Those six programs are:

- Vortex Advisory and Wake Vortex Avoidance Systems (VAS/WVAS)
- ATC System Automation features related to airport capacity (Metering and Spacing (M&S) plus automation aids to the controller)

- Discrete Address Beacon System (DABS)
- Airport Surface Traffic Control (ASTC) -- including Airport Surface Detection Equipment (ASDE-3) and Tower Automated Ground Surveillance (TAGS)
- Area Navigation (RNAV)
- Microwave Landing System (MLS)

Section 2 describes the six E&D elements. The general methodology followed in analyzing the impact of these elements is given in Section 3. Finally the potential benefits of the E&D elements at the eight airports are summarized in Sections 4 and 5.

2. DESCRIPTION OF E&D ELEMENTS

Program descriptions for WVAS, ATC System Automation, DABS, ASTC, RNAV and MLS are contained in the following subsections. Additional information is found in References 3-6, 15-17, 23, 28.

2.1 Wake Vortex Avoidance System (WVAS)

The major objective of the FAA's wake vortex program is to develop ground-based prediction/detection systems which will allow for decreased longitudinal spacing between aircraft when trailing wake vortices do not present a hazard to following aircraft. To develop a system capable of reducing separations by predicting vortex motion it was first necessary to learn enough about the life, decay and movement of vortices as a function of generating aircraft and meteorological conditions so that such predictions could be made. Using predictive data, the approach controller can then establish aircraft spacing based on the expected vortex transport and decay conditions in the runway approach corridor.

Currently, there are two levels of WVAS installations envisioned. The first level called the Vortex Advisory System (VAS) utilizes wind speed and direction information to permit the controller to reduce aircraft separations during those times when vortices either quickly decay or move from the approach corridor. As shown in Figure 2-1, the prototype O'Hare meteorological network consists of six 50-foot towers, one of which is located near the middle marker at each of the operating approach corridors, which are used to measure wind parameters. Multiple towers are considered necessary since tests at O'Hare and at the JFK International Airport have shown that the inhomogeneity of the atmosphere precludes the use of a single centrally located sensor for the measurements of the wind parameters.

A multiplexer successively samples the sensor outputs and converts these to a parallel digital data word which in turn is serialized and transmitted over standard existing FAA lines to a central facility where receivers reconvert the data to a parallel format for input to a VAS processor. The sensor outputs are sampled at two samples per second with a one minute running average maintained on each sensor. The averaged meteorological data from the runway in use is then compared to a meteorological vortex advisory system algorithm and the vortex separation requirements determined. Long term sampling and hysteresis are used to prevent frequent and erroneous changes in the indicated vortex condition. It should be noted that the vortex advisory

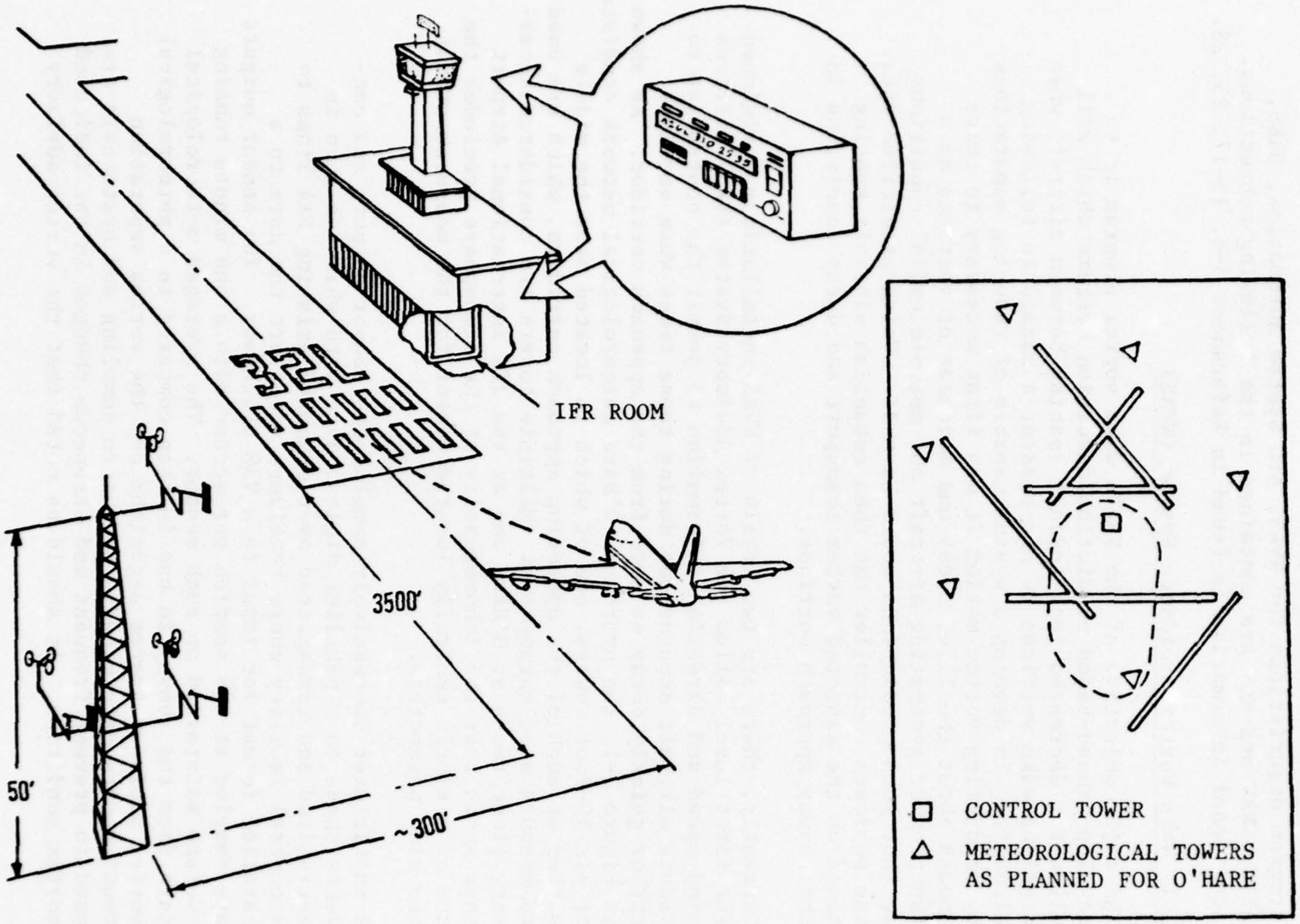

FIGURE 2-1
VORTEX ADVISORY SYSTEM (VAS) CONCEPT

system design represents a "first-cut" system design. It is anticipated that both hardware and software changes will be required during the operational feasibility evaluation phase.

Wake vortex program plans also include the development of a more sophisticated automated system with detection and prediction capabilities, called the Wake Vortex Avoidance System. Figure 2-2 shows a conceptual block diagram of the automated wake vortex avoidance system.

Preliminary design thinking indicates that the WVAS may operate in the following manner. Vortex detection and meteorological data will be continually input into the WVAS dedicated VAS processor. Stored within the VAS processor would be the vortex behavior algorithm and aircraft spacing criteria. Spacing between various aircraft types would be specified as a function of the vortex behavior algorithm and the hazard associated with each aircraft type. A spacing matrix is generated and provided to the ARTS III computer where it would be used along with metering and sequencing criteria to establish minimum spacings in the terminal area compatible with safety and operations requirements. The predicted information should be provided to ARTS III with a lead of about 10-15 minutes to allow for proper metering and handoff procedures in the terminal areas.

The spacings provided must also be sufficiently insensitive to minor meteorological variations so that the spacing matrix is not continually changing, since this would prevent orderly sequencing and metering operations.

Concurrent with providing spacing information to ARTS III, the WVAS minicomputer would be continually monitoring wake vortex sensors which are tracking the vortices in real time. When a vortex moves contrary to that previously estimated by the predictive algorithm and remains in the flight path, a signal could be simultaneously sent to ARTS III, the tower and the affected aircraft. For the predictive system to operate effectively, the probability of such a situation occurring must be quite low. To determine the probability of a vortex moving counter to the prediction requires knowledge of the sensitivity of the vortex behavior model to minor changes in its critical parameters. Once this sensitivity figure is established, it should be possible to reduce the probability of a vortex moving counter to the prediction by adding an additional safety margin to the critical behavior model parameters.

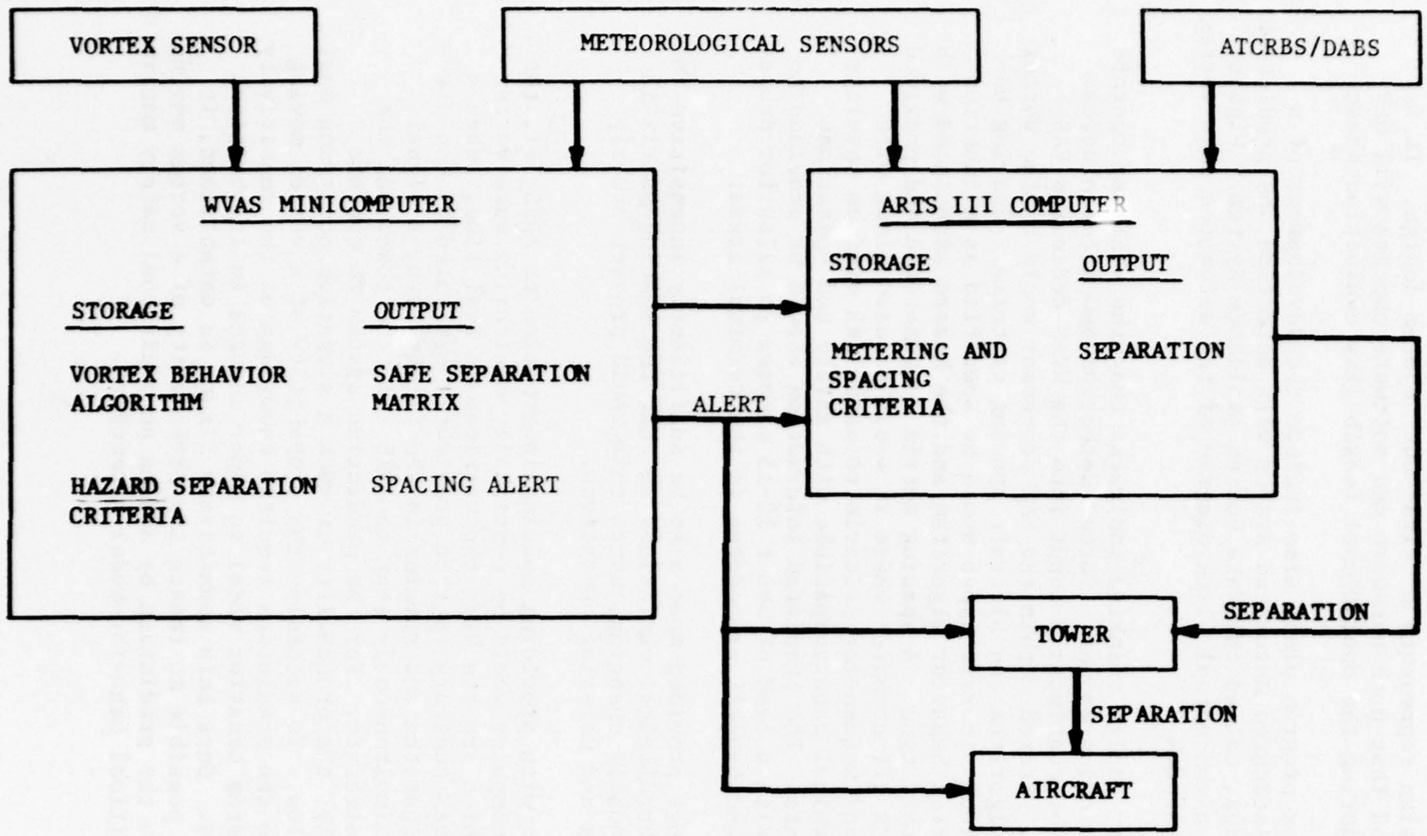

FIGURE 2-2
WAKE VORTEX AVOIDANCE SYSTEM (WVAS) CONCEPT

To obtain maximum benefit from the WVAS, an effective metering and sequencing program is essential, since controllers would not have the capability to fully utilize the matrix output. The matrix conceivably would be complex and change relatively frequently, requiring a computer to store, utilize, and display optimum spacing data.

2.2 ATC System Automation

The automation aids to the controller, when fully developed, could include digitized displays of aircraft separations, computer generated alarms, and WVAS information display. The ATC System Automation program plans to develop metering and spacing (M&S) systems evolving from the current manual system to an improved (Advanced) M&S system through a Basic (implementable) M&S system. The purpose of the M&S systems is to decrease the delivery error of aircraft at the gate of the final approach in order to provide higher precision for the aircraft separations uniformly over time.

An initial M&S system for Denver is currently under test design and evaluation. It will address a single approach to a single runway. It employs path stretching and shortening (with some speed control) between way points defined on arrival routes. The system will provide control instructions to the controller displays for voice transmission to the pilot. The path control of aircraft over the way points on the arrival routes will increase the delivery accuracy of the aircraft. Such an increase will help reduce the buffer required to ensure non-violation of the separation standards. The reduction in the required buffer decreases actual spacings between aircraft and thus aids in increasing the capacity.

An implementable M&S system will evolve from the first Denver design. It will be based on the ARTS IIIA (enhanced) system and will be oriented toward controlling traffic for a single airport (i.e., satellite airports are not considered). The system will incorporate the ability of handling changes in runway configurations. With the basic (implementable) M&S system, the controller will be required to manually input the desired separation between arriving aircraft to obtain appropriate departure gaps. The controller has the freedom to change the desired departure gaps to accommodate changing traffic situations through appropriate input to the M&S system. The interface with the Vortex Advisory System is also conducted

manually through appropriate two state (RED/GREEN) input depending on the indication of the VAS output. The basic (implementable) M&S system is expected to decrease the interarrival error between aircraft from the current 18 seconds (one standard deviation) to 11 seconds (one standard deviation) (Reference 7).

An improved M&S system, expected to evolve from the basic (implementable) system, enhances the performance with better delivery accuracy and added system capabilities. This system will be able to control multiple dependent arrivals (up to 3 streams). In addition, the handling of the departure queue (i.e., creating departure gaps) will be automated, as will the interface with the WVAS installation. The presence of the data link may be used to provide routine control messages to the pilot in an automated mode. The improved M&S system is expected to interact with the ASTC system to provide a more efficient interleaving of arrivals and departures. The interarrival error between aircraft is expected to decrease to 8 seconds (one standard deviation) under the improved M&S system (Reference 7).

2.3 Discrete Address Beacon System (DABS)

DABS provides a technical improvement to today's Air Traffic Control Radar Beacon System (ATCRBS) which will be fully compatible with ATCRBS airborne transponders and ground-based interrogators. DABS is designed to reduce the surveillance error and provide a ground-air-ground data link with the capability of addressing each aircraft in a discrete manner. The data link will assist in reducing the voice communication workload of the controller, and will provide the means of automating the transmission of routine messages between the ground and the aircraft. The possibility of using the data link for the automatic transmission of the metering and spacing messages will be investigated as a way to further decrease controller workload and insure the timely delivery of those messages.

2.4 Airport Surface Traffic Control (ASTC)

The ASTC program is being developed to provide the ground controller with improved automated display of airport surface traffic. The need for an automated improved airport surface traffic control becomes more important in limited visibility conditions. There are two basic aids being developed.

ASDE-3 (Airport Surface Detection Equipment), a new ground surveillance radar, will display the position of each surface vehicle on the airport surface to the ground controller. In heavy traffic, however, some degree of pilot position reporting may be required due to lack of identity (on ASDE-3 display). The same basic information that is given to the ground controller may also be given to the local controller. ASDE-3 is to be a modern solid state radar. The specified MTBF will be 2,000 hours, a 10 to 1 improvement over the modified ASDE-2. The unit will operate at about 15 GHz versus the 24 GHz of ASDE-2, and have a redesigned radome to improve performance during rainfall. It will also have display enhancement features to eliminate surface returns (except for valid targets).

TAGS (Tower Automated Ground Surveillance) is a longer term program for improving airport surveillance. Its operation is to restore the ground control capacity lost through bad cab visibility even when an ASDE is available. TAGS will be designed to present a clear uncluttered plan view display of the airport and label each ATCRBS (DABS) beacon equipped target with flight identity. Target detection and identity correlation problems present with ASDE should be eliminated. In addition, since TAGS will be a cooperative system (relying on an on-board beacon), it will be virtually weather immune, eliminating rainfall penetration problems associated with passive radars (even ASDE-3).

Mechanization of TAGS will probably be based on new sensor technology to interrogate existing ATCRBS transponders on board the aircraft and determine their surface location and identity by trilateration. Figure 2-3 presents a possible display format for TAGS. The figure shows a wholly synthetic display such as would be used if TAGS were to rely solely on the ATCRBS (DABS) sensor for information and thus replace ASDE.

The decision as to whether ASDE should be replaced by TAGS or used in conjunction with TAGS has not yet been made. A TAGS system which would use ASDE-3 for an analog radar target and the ATCRBS (DABS) sensor for flight identity to tag the radar image is under consideration. As currently planned, the combined sensor system (hybrid system) would be an option in the TAGS engineering model development program. One advantage of such a hybrid system is that if either subsystem fails, the other system would provide a backup display presentation -- either ASDE target or direct interrogation tags with leaders pointing to the approximate target locations.

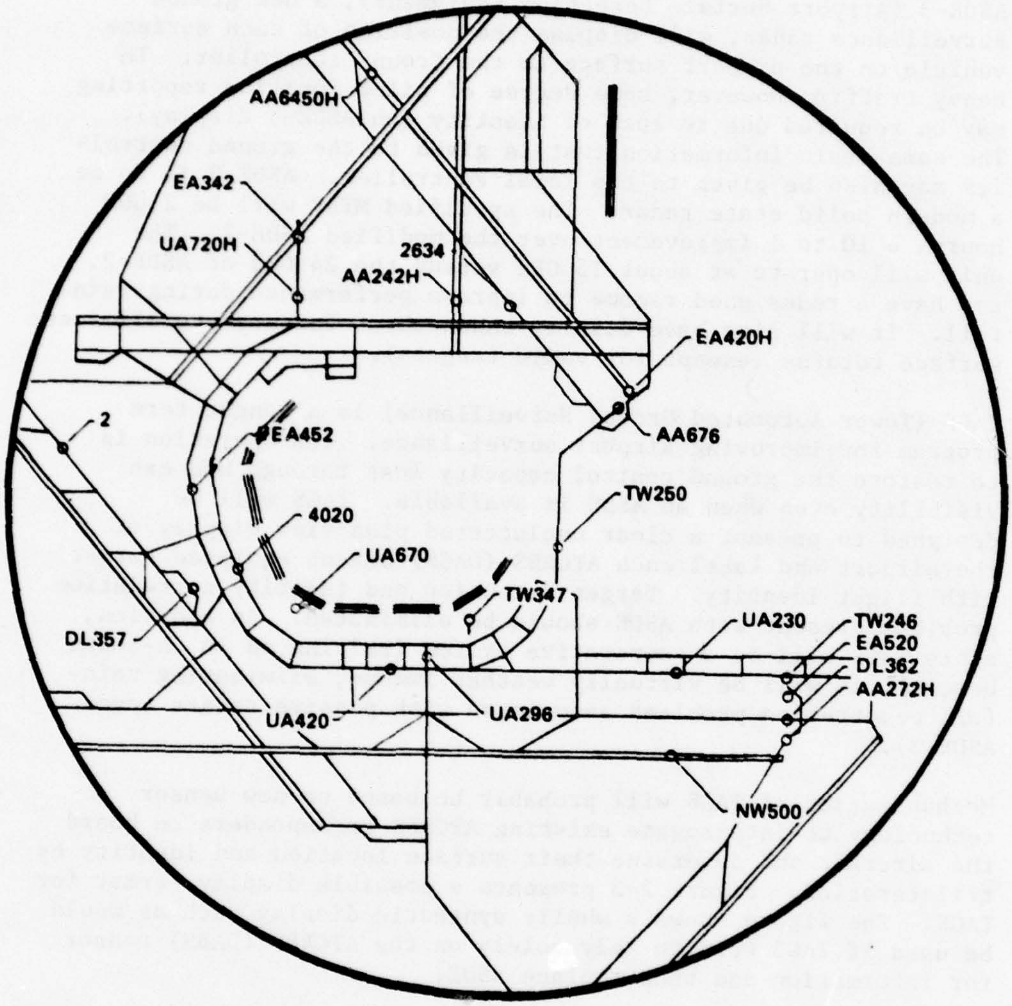

FIGURE 2-3
PRELIMINARY TAGS DISPLAY FOR GROUND CONTROLLER

The E&D element closely tied to TAGS is Metering and Spacing. The current local control problems arise when the demand forces the controller to try to release departures between the closely spaced arrivals on dependent runways. In order to increase arrival rates, M&S will space more arrivals closer together. This will expand the problems of local control. Unless timing aids can be supplied (i.e., TAGS), the departure capacity may not be maintainable at the current levels. Excess arrivals can bog down the airport and may not be of value without the ability to interleave arrival and departure use of the runway in a manner more precise than is necessary in today's environment. This problem has not been examined in detail.

2.5 Area Navigation (RNAV)

In the present ATC system, navigation is performed along a series of straight line courses known as radials which extend outward from VORTAC and VOR ground stations. This constrains all routes to a series of straight line segments joining one VOR/VORTAC to another. The term Area Navigation (RNAV) refers to an airborne navigation system which provides navigation along a direct course to any destination or to any intermediate way point. The term 2D is commonly used to refer to RNAV systems (currently in use) which provide navigation in the horizontal plane to a point defined in two dimensions by latitude and longitude or a bearing and a distance from a VOR/VORTAC ground station, or through use in INS or Omega systems. The 3D-RNAV (or VNAV) system adds the third vertical dimension of altitude, and 4D-RNAV systems add the fourth dimension of time. RNAV will enable aircraft to fly from one designated way point to another within the terminal area without being told when and where to turn and change altitude by the controller by using (1) delay fan, (2) direct to next way point, (3) parallel offsets on base leg, and (4) multiple discrete parallel departure paths. Figure 2-4 illustrates the concepts for use of RNAV in terminal area. The RNAV routes may interact with the M&S system in defining the M&S way points, and the RNAV system may provide better aircraft location data to the M&S system. RNAV avionics are available on the market and there are limited provisions for 2D RNAV routes in the ATC system.

2.6 Microwave Landing System (MLS)

MLS is to be an air-derived precision navigation system operating in the microwave (C-band) region of the frequency spectrum which provides precise azimuth and elevation angle data as well as range (DME) data over a wide coverage volume (azimuth and elevation angles). The data is suitable for visual display to

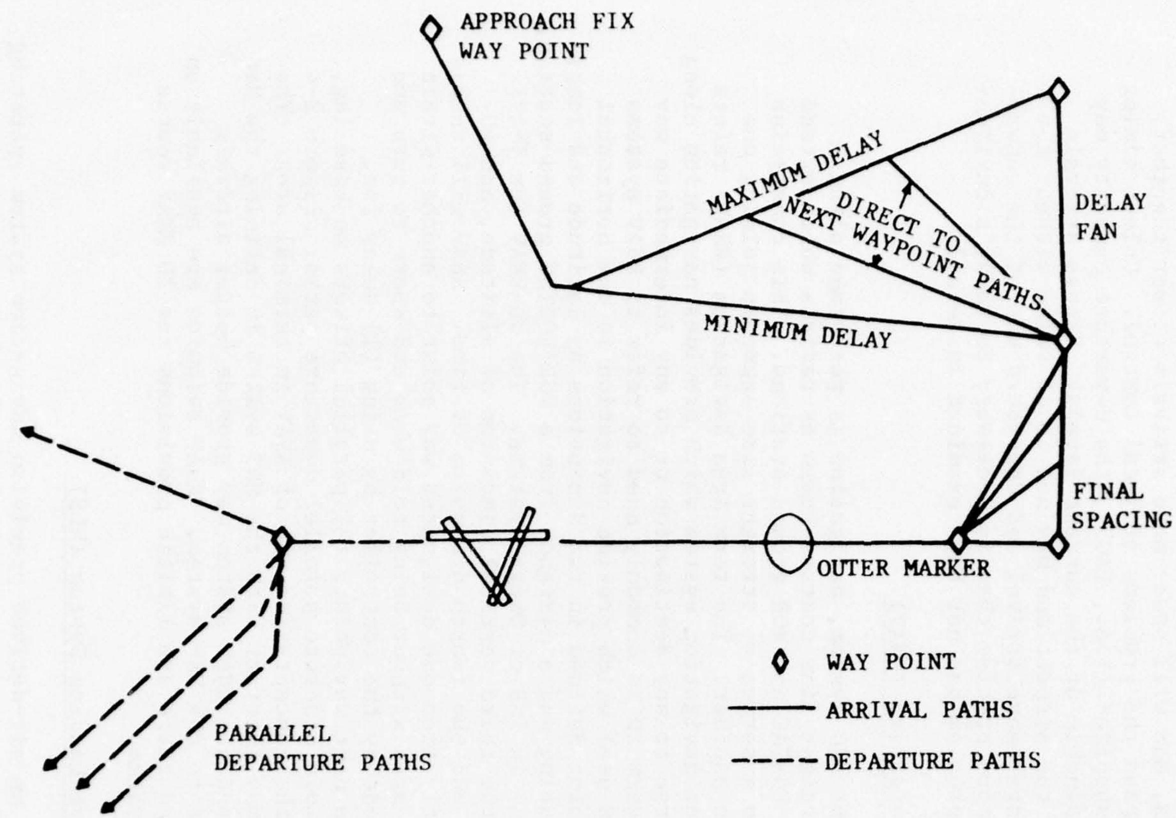

FIGURE 2-4
ILLUSTRATION OF CONCEPTS FOR USE OF RNAV IN TERMINAL AREA ATC

facilitate manual approach and landing in poor visibility conditions, and may be provided as an input to the automatic flight control system for fully automatic approach and landing. A simplified schematic presentation of the MLS is shown in Figure 2-5. The system can be installed with a number of levels of sophistication: from the capability to define a single path vertically and horizontally to a capability to define multiple paths.

The United States Time Reference Scanning Beam (TRSB) MLS is based on a technique in which narrow fan beams scan through the coverage volume in alternate directions. The beams are scanned at high speed and consist of a single, uniform, modulated, continuous radio frequency transmission. The time interval between the pulses is proportional to the angular position of the aircraft with respect to the runway. High data rates make it possible to design simple airborne processors that can minimize any multipath effects on guidance signals.

Precision azimuth angle guidance is provided to at least $\pm 40^{\circ}$, or a narrower sector if desired (AZ-1 in Figure 2-5). Precision elevation angle guidance is provided from 1° to 20° in elevation over the same sector that provides azimuth angle guidance (EL-1). Precision missed approach guidance, referenced to the runway centerline, is provided to at least $\pm 20^{\circ}$ (AZ-2). Flare guidance may also be provided (EL-2). Range information is determined on board suitably equipped aircraft from DME equipment allocated with the MLS azimuth system (AZ-1).

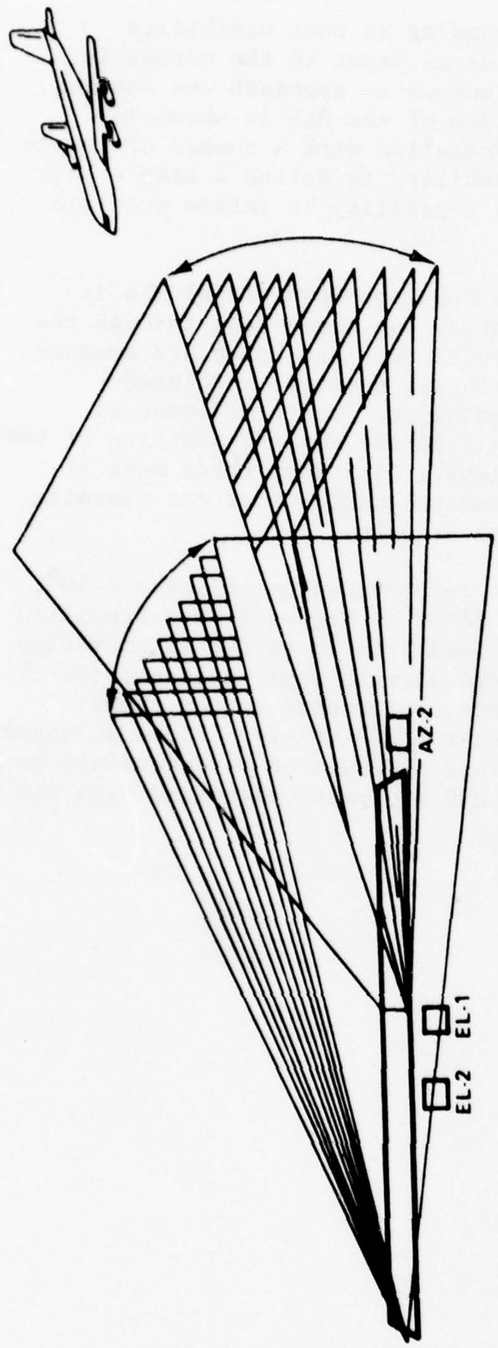

FIGURE 2-5
MICROWAVE LANDING SYSTEM

3. METHODOLOGY

Evaluation of the impacts of ASTC, RNAV and MLS was made on an airport specific basis. Where possible, results from previous airport specific studies conducted by the FAA or other contractors under FAA sponsorship were used. Visits to some of the airports for an on-site analysis were used to supplement previous studies and current analyses. Such visits were especially useful in making an appraisal of MLS benefits. The summary of results of this evaluation for the eight airports is given in Section 5.

Evaluation of the impact of WVAS, ATC System Automation and DABS on airport capacity required a characterization of the performance of these elements to reflect the changes in performance that is expected as evolutionary improvements are realized. For this purpose, at the start of the airport studies, the AEM-100 Division of the Office of Systems Engineering Management, FAA, designated certain groupings of improvements to reflect expected time of availability. These groupings are shown in Table 3-1.

In the near term (Group 2), the Vortex Advisory System (VAS) and Basic Metering and Spacing are expected to improve M&S delivery accuracy and permit reductions in the 4, 5, and 6 nmi IFR wake vortex separations when VAS observations of meteorological conditions indicate it is safe to do so, while maintaining the current 3 nmi minimum IFR separation standard for aircraft pairs not impacted by wake vortex.

In the intermediate term (Group 3), Basic Metering and Spacing is expected to be supplemented by the Wake Vortex Avoidance System and some improved surveillance capabilities for the controller (e.g., digitized display of separation measures, computer generated alarms). In this analysis, the basic IFR arrival separation standard is reduced to 2.5 nmi for those aircraft pairs currently governed by the 3 nmi separation standard. Other aircraft pairs, separated by more than 3 nmi today because of wake vortex hazard, are assumed to have significantly reduced separation requirements as well, but to a level above 2.5 nmi. Reduced departure separation requirements are also assumed.

In the far term (Group 4), it is anticipated that the Metering and Spacing system will evolve to an improved capability, and the Discrete Address Beacon System will be introduced. The basic IFR arrival separation standard is assumed to be reduced to as low a 2 nmi for the least vortex impacted aircraft pairs (e.g., large aircraft following small aircraft). For other

TABLE 3-1
AVAILABILITY OF FUTURE ATC EQUIPMENT

TIME PERIOD	AVAILABLE E&D ELEMENTS	MINIMUM ARRIVAL IFR SEPARATION (LEAST VORTED IMPACTED PAIRS)	EQUIPMENT GROUP
NEAR TERM:	Vortex Advisory System Basic Metering and Spacing*	3 nmi	2
INTERMEDIATE TERM:	Wake Vortex Avoidance System Basic Metering and Spacing* Improved Surveillance**	2.5 nmi	3
FAR TERM:	Wake Vortex Avoidance System Improved Metering and Spacing Discrete Address Beacon System	2 nmi	4

*Basic (Implementable) Metering and Spacing System
**Assumed to include automation aids to the controller (e.g., digitized display of separation measures, computer generated alarms, etc.)

aircraft pairs, spacings are also further reduced in this analysis, but remain at values larger than 2 nmi. Departure separations are assumed to all be reduced to 60 seconds. Obviously, this far term capability requires extensive E&D effort to arrive at an implementable state.

For each of these time frames, performance characteristics have been developed in detail in Reference 2 for VFR as well as IFR conditions, and are given in Appendix A. These performance measures, plus airport specific runway operating strategies, exit location and usage, and aircraft mix, can then be used as inputs to the FAA capacity model to estimate future capacities under both safe (green light) and fall back (red light) conditions of WVAS.

The capacity calculations for the Task Forces were generally made only for near term (Group 2) and far term (Group 4) cases. These are reported in the body of this report. Some intermediate term (Group 3) values were run later; these are included in Appendix B.

It needs to be emphasized at this point that the assumptions used in this analysis as to the reduction in longitudinal spacing under IFR conditions due to VAS/WVAS were substantially less than the reductions stated as being the goals of the VAS/WVAS E&D programs. For example, the objective of the VAS program* is to allow a spacing of 3 nmi between all pairs of aircraft on final approach under VAS "green light" conditions. The assumption made in these airport specific analyses was that larger separations would still be required between certain types of aircraft, up to as much as 5 nmi for a small aircraft following a heavy aircraft. Similarly, the stated objective of the WVAS program is to reduce separations to as little as 2 nmi. The assumption made in this study was that while 2 nmi might be acceptable between some aircraft pairs, larger separations would be required between other pairs--for example, 3.7 nmi for a small aircraft following a heavy aircraft, and 3.0 nmi for a large aircraft following a heavy aircraft. The exact separations used are shown in Appendix A.

For convenience in describing impacts in Sections 4 and 5, a sketch of runway layouts at the eight airports is given in Figure 3-1. This figure is reproduced as Figure E-1, which may be folded out for convenient reference in reading the remainder of this report.

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*As of January 1978.

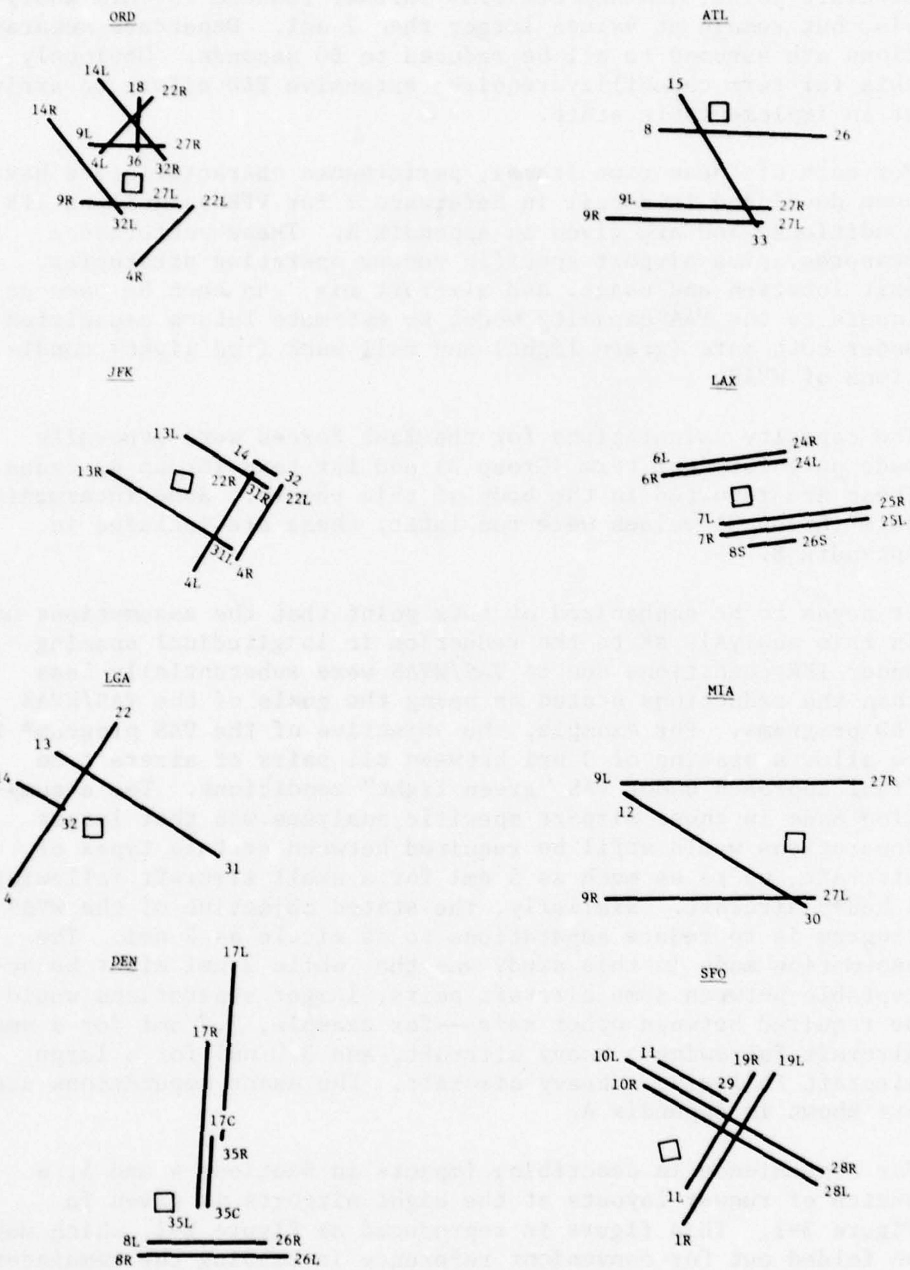

FIGURE 3-1
EIGHT AIRPORT RUNWAY LAYOUT SKETCHES

4. IMPACT OF WVAS, ATC SYSTEM AUTOMATION AND DABS

The impact of WVAS, ATC System Automation and DABS through changes in aircraft spacing on airport capacity is given in this section for the time frames representative of Groups 2 and 4 E&D equipage.

The capacity loss resulting from an increasing percentage of heavy aircraft in the future, assuming no E&D deployment, can be very significant at some airports. This is illustrated in Figure 4-1 (a detailed table is provided in Appendix B). The capacity losses, which generally range from 3-10%, are particularly significant in VFR at DEN, where the increases in heavy aircraft result in a 17% decrease in airport capacity. This is due to the close parallel runways which cause vortex separation rules to be applied to approaches on separate runways (as well as to approaches to the same runway). Thus, the insertion of a heavy aircraft increases spacing on both runways. In this case, E&D elements provide little or no actual capacity improvement versus today; most of the Group 4 VFR capacity gain is to recover the capacity that would otherwise be lost in the future, due to the increasing percentage of heavy aircraft.

The capacity gains at the eight airports, as a result of the implementation of these E&D equipment groups, are shown in Figures 4-2 and 4-3. Values are shown for Groups 2 and 4 with the reduced spacings permitted with VAS/WVAS. Values are also shown for "fallback" conditions of larger separations when VAS/WVAS indicates hazardous vortex conditions at the lower spacings. Capacity gains are calculated as a percentage, by comparing the capacity of the appropriate future ATC environment (Group 2 or 4; full E&D or fallback vortex rules) with the capacity of today's ATC system, but reflecting future aircraft fleet mix. For each airport, the gain shown in the figures represents the midpoint of the capacity values for the several configurations chosen by the Airport Task Force to be representative of the normal range of capabilities. For the Group 4 time frame, average capacity gains range up to 21% in VFR and 51% in IFR. Further discussion of these values is given in subsequent paragraphs. Detailed values are provided in Appendix B.

For VFR, the capacity gains are modest in the Group 2 E&D time frame. In the Group 4 time frame, the gain is in the 10-20% range. The gain under increased vortex separation rules (fall back) is approximately half this amount. For IFR, the gains are much larger. This reflects in large part the fact that E&D elements primarily address an IFR capacity need, and only

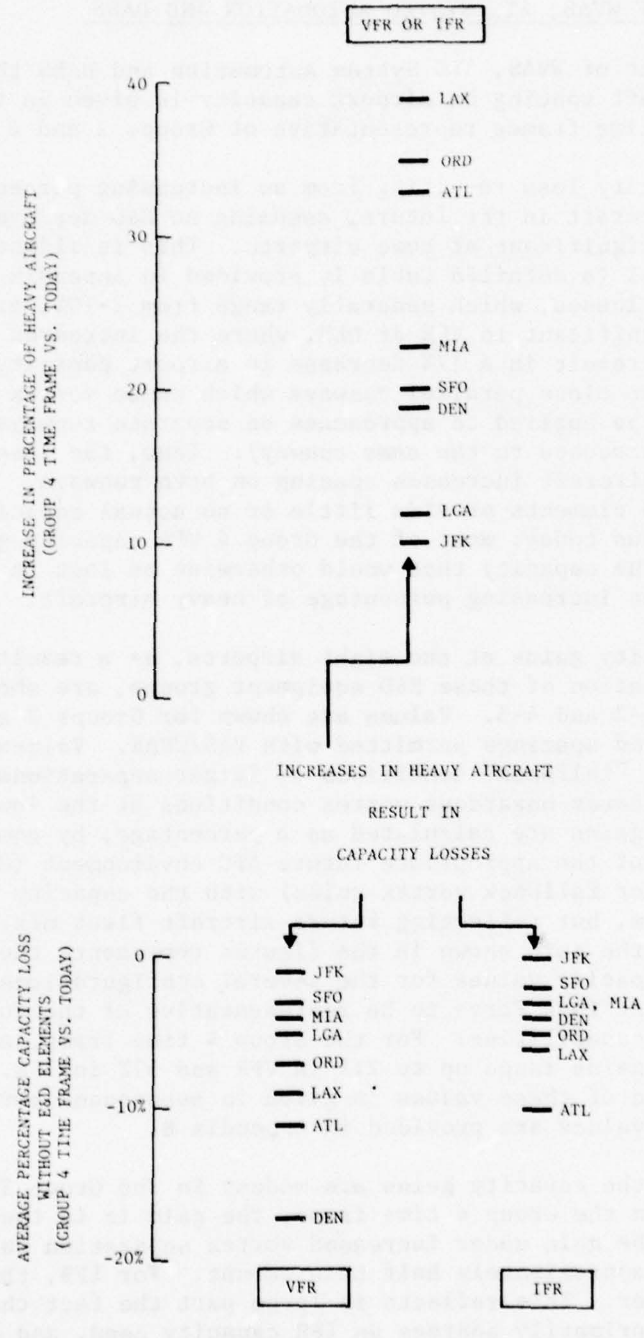

FIGURE 4-1
CAPACITY LOSS DUE TO INCREASING NUMBER OF HEAVY AIRCRAFT

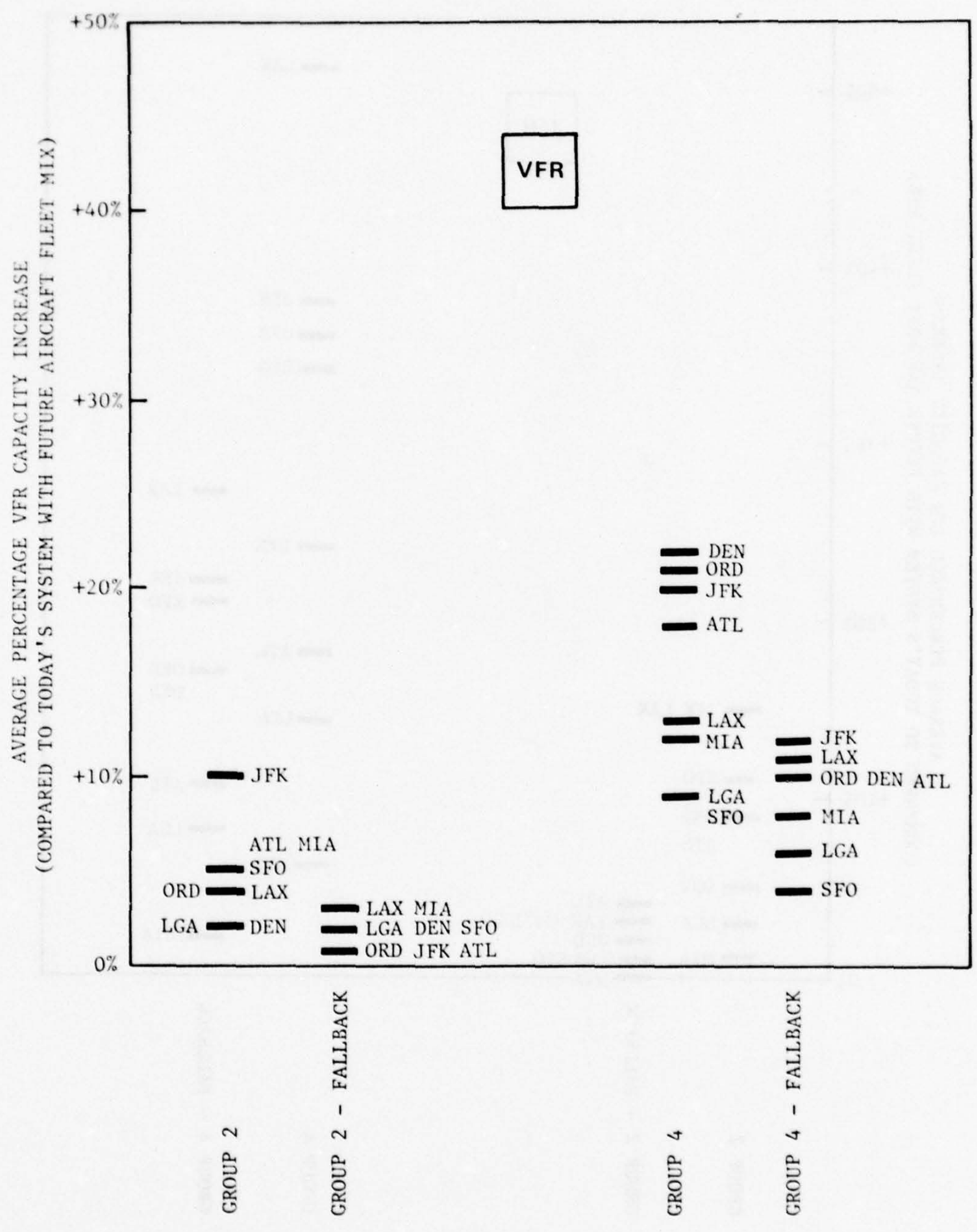

FIGURE 4-2
AVERAGE PERCENTAGE VFR CAPACITY INCREASE

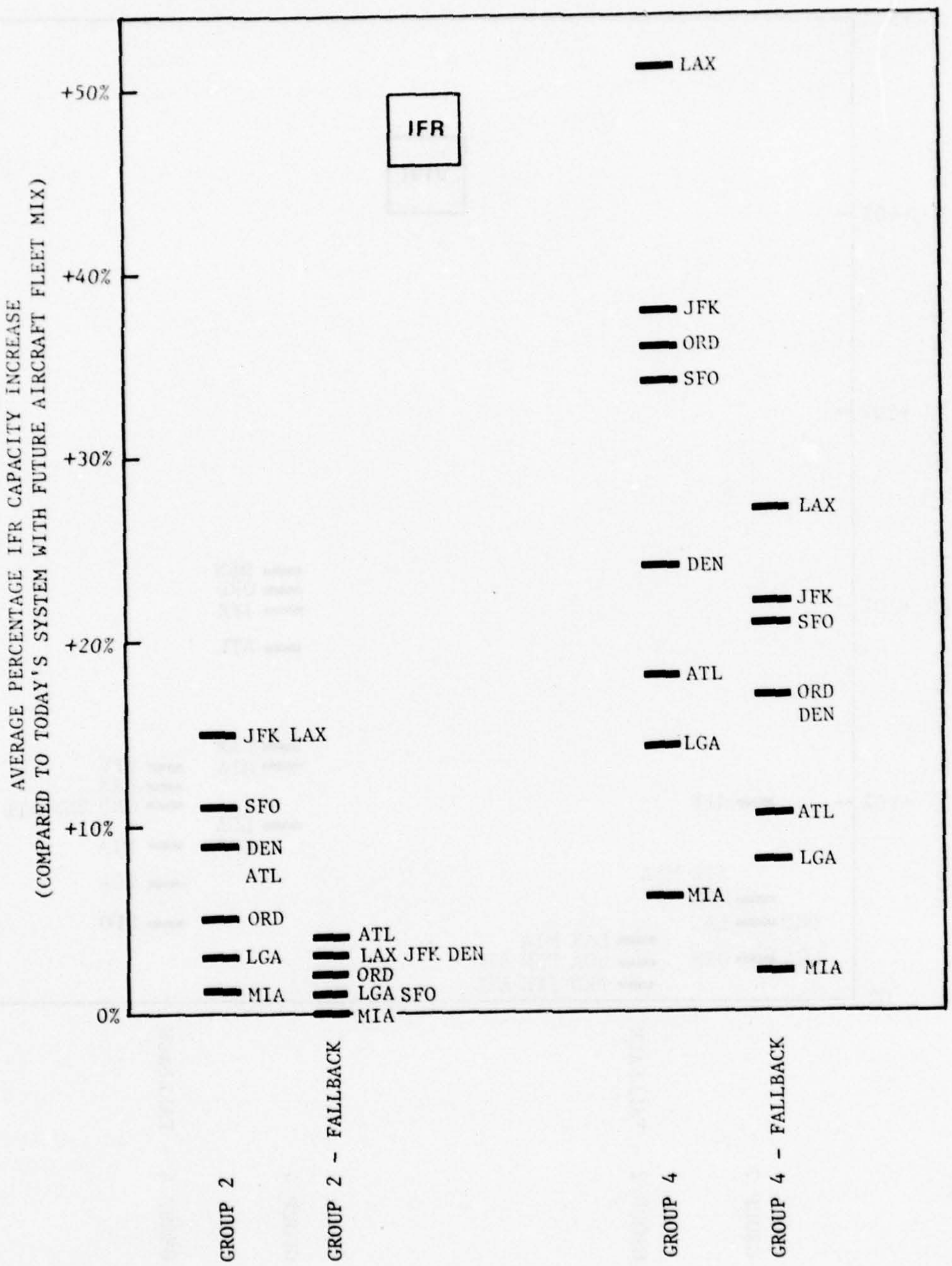

FIGURE 4-3
AVERAGE PERCENTAGE IFR CAPACITY INCREASE

secondarily assist the VFR case. The VFR system today also operates much closer to the constraints of runway usage (versus the often larger IFR separation requirements).

The values of airport capacity gains are largely dependent on the significant runway configurations evaluated by the Task Forces. Arrival only runways, dual-lane configurations and crossing configurations with short times to crossing permit the greatest decreases in separations, and thus exhibit the largest capacity gains. Thus, under IFR conditions LAX, JFK, ORD and SFO have such configurations and show large benefits. The DEN capacity values represent averages of an arrival only/departure only value on one hand with a dual-lane which is restricted to look like an arrival/departure runway on the other hand. The first is a good configuration (from an E&D impact point of view); the second is a poor configuration. The remaining three airports, ATL, LGA and MIA, are dominated by an arrival/departure runway (poor from E&D impact point of view). ATL, in particular, shows a balancing of departures between north and south runways today which will not be possible in the future. The relative impact of different runway configurations is further illustrated, based upon the methodology of Reference 8, in Appendix C.

It should be noted that the average capacity gains shown represent a midpoint of a wide range of values at many of the airports. This is illustrated, for Group 4, in Figure 4-4. This shows that particularly in IFR at ORD and LGA, there is a wide range of capacity gains. For ORD, this reflects a wide variety of crossing configurations. For LGA, it reflects the difference between a good crossing configuration (high capacity gains) and an arrival/departure runway (low capacity gains).

Finally, it should be remembered that the capacity values shown reflect not only configuration type, E&D performance capability, and aircraft mix, but also other airport specific considerations that impact capacity. Notable among these is runway occupancy time. Today's observations of occupancy times have been used in the capacity calculation for all equipment groups. That is, no account was taken of possible future improvements due to high-speed exits and/or pilot technique. At some airports (for example DEN) runway occupancy times today are large. This limits the estimated E&D impact, particularly in the Group 4 time frame where arrival standards are as low as 2 nmi. Any future reduction in runway occupancy time, due to refined technique, additional exits and/or new technology, would help maximize the potential benefits of the capacity related E&D programs.

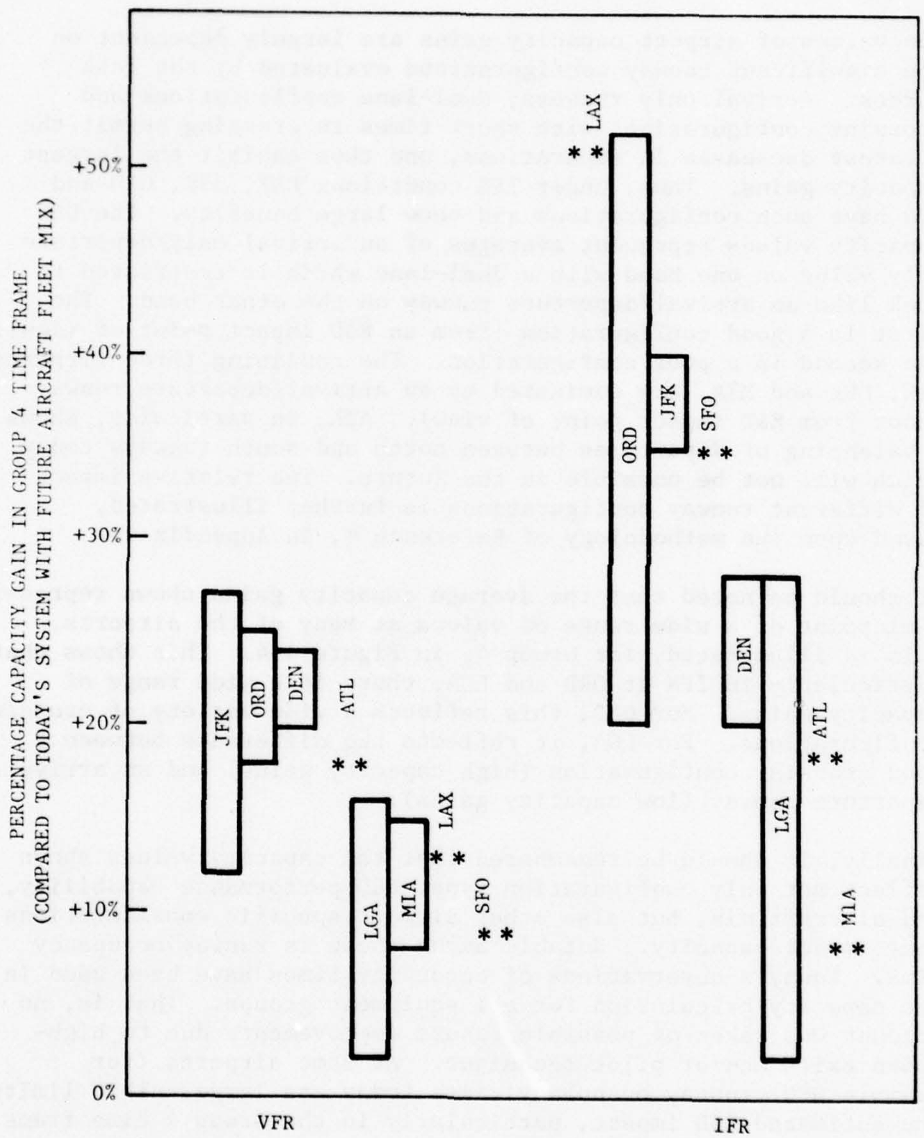

FIGURE 4-4
VARIATION IN CAPACITY GAIN BY RUNWAY

The capacity impacts of the Group 2 and Group 4 E&D elements are summarized in Table 4-1. The Group 2 elements (VAS, Basic M&S) provide up to 10% capacity gain in VFR and up to 15% gain in IFR. Fall back gains are up to 4%. The Group 4 E&D elements (WVAS, Improved M&S, DABS) provide up to 21% capacity gain in VFR and up to 51% gain in IFR. Fall back capacity gains are about half these values.

TABLE 4-1
SUMMARY OF IMPACT OF E&D ELEMENTS ON AIRPORT CAPACITY AT THE EIGHT AIRPORTS*

	GROUP 2	GROUP 4
	VAS + BASIC M&S	WVAS + IMPROVED M&S + DABS
VFR - FULL E&D**	2% to 10%	9% to 21%
- FALL BACK	0% to 4%	4% to 12%
IFR - FULL E&D	0% to 15%	5% to 51%
- FALL BACK	0% to 4%	2% to 27%

*COMPARED TO TODAY'S ATC SYSTEM WITH FUTURE AIRCRAFT FLEET MIX.

**THE TERM "FULL E&D" REFERS TO THE CONDITION WHERE VAS (GROUP 2 OR WVAS (GROUP 4) INDICATES THAT REDUCED SEPARATIONS ARE SAFE. THE TERMS "FALL BACK" REFERS TO CONDITIONS WHERE VAS OR WVAS INDICATES THAT ADDITIONAL SPACING IS REQUIRED TO AVOID ENCOUNTERS WITH WAKE VORTICES.

5. IMPACTS OF ASTC, RNAV AND MLS

A summary of the impacts of ASTC, RNAV and MLS at the eight airports is presented in this section. The detailed development of these impacts is found in the individual airport reports, MTR-7350, Volumes 1 through VII. The results are based upon airport specific analyses done for the case study efforts, and on previous studies either performed by the FAA or under the sponsorship of the FAA (References 10-16 for ASTC, 17-23 for RNAV, and 24-32 for MLS).

The areas of potential impact of ASTC, RNAV and MLS are summarized in Table 5-1. The impacts identified at the eight airports are discussed in the following subsections.

5.1 ASTC Impacts

The Airport Surface Traffic Control (ASTC) System controls the movement of traffic to, through, on and off airport runways and taxiways; it encompasses people, procedures, and equipment. The areas of potential impact, as summarized in Table 5-1, are described below.

Today, when the local and ground controllers located in the tower cab at all but twelve airports, are unable to see all or portions of the airport surface due to bad weather (fog, snow, etc.), they must rely on the pilot's verbal position reports issued via voice radio to maintain a mental "picture" of the traffic flow. The other twelve airports have Airport Surface Detection Equipment (ASDE-2) (a primary ground surveillance radar giving a plan view display of the surface traffic situation) to assist the controller during periods of poor visibility. A new radar, designated ASDE-3, will provide improvements in rainfall penetration, reliability and maintainability, and display enhancement. The use of ASDE (either ASDE-2 or ASDE-3) is described below.

The use of pilot position reports today as the sole means of surveillance during periods of low visibility limits the capacity of both local and ground controllers. For local control, the problem is one of determining when and where certain events are occurring. In handling arrivals, local control must be able to determine when an arrival is at the runway threshold, when it has landed, when it is committed to its turnoff, and when it has cleared the runway. In handling departures, the local controller must be able to determine that the next departure

TABLE 5-1
POTENTIAL IMPACTS OF ASTC, RNAV, MLS

ASTC

ASDE-3 -- RELIABILITY, MAINTAINABILITY, DISPLAY IMPROVEMENTS

-- LOCAL CONTROLLER - CAPACITY RECOVERY
REDUCED WORKLOAD

-- GROUND CONTROLLER - IMPROVEMENT IN CAPABILITY VS POSITION REPORTS
- REDUCED WORKLOAD

TAGS -- GROUND CONTROLLER - CAPABILITY DOES NOT DEGRADE IN POOR VISIBILITY

RNAV

FUEL AND TIME SAVINGS

CONTROLLER WORKLOAD REDUCTIONS

MLS

ADDITIONAL FREQUENCY ASSIGNMENTS/EASE OF MAINTENANCE

EASE OF SITING

REDUCED LOCALIZER MULTIPATH INTERFERENCE

REDUCED GLIDE SLOPE CRITICAL AREAS

REDUCED AIRSPACE CONFLICTS

REDUCED NOISE IMPACT BY USE OF CURVED PATHS

ADDITIONAL REDUCED MINIMA WITH PRECISION GUIDANCE

ENHANCED FAIL OPERATIONAL CAPABILITY

ENHANCED PRECISE TURN CAPABILITY

is in position on the runway and holding, that it has promptly started its roll when given takeoff clearance, and that the departure has lifted off. To the extent that the local controller cannot visually obtain this timing information, he asks the pilots to provide the information by means of the voice channel. The pilot information is not as precise as that obtained by direct observation, and runway capacity is lost. The extent of the capacity loss depends on the type of runway configuration being operated and the percentage of heavy aircraft that operate into the airport. ASDE provides the required timing information and essentially allows the local controller to handle as many aircraft under low visibility as he can handle without ASDE under good visibility conditions.

For ground control, the problem is one of maintaining a mental "picture" of the surface traffic. To the extent ground control is not in visual contact with the surface traffic, reliance is placed on position reports from the pilots at critical junctures in their assigned routes in order to monitor the traffic and maintain control. With ASDE, the controller can now see the surface traffic but has trouble associating the right flight number with the right radar target. Errors in the association of flight numbers with targets can lead to controller confusion in confirming that each aircraft is following its assigned route, confusion as to who to call in response to some critical traffic situation shown on the display, or confusion as to which target on the display shows the current location of a pilot calling for new/revised routing instructions. To reduce this confusion, the controller uses his communication channel once again. The result is that ASDE improves ground control capacity in low visibility conditions but that the voice channel saturates before the capacity reaches its good visibility level. To return the ground control capacity to its good visibility level, the displayed targets must be tagged with their flight numbers. This is the purpose of the TAGS (Tower Automated Ground Surveillance) system and its associated display.

The potential impacts of ASTC identified at the eight airports are summarized in Table 5-2. For the airports with a current ASDE, there are significant improvements in reliability, maintainability and display by upgrading to ASDE-3. These enable the benefits of an ASDE to be more available and more reliable. For the local controller, capacity recovery is experienced at ATL, under those conditions when the current ASDE-2 experiences whiteout or reliability problems. Workload reductions would also result at ATL as the current degree of necessary coordination between ground and local control is

TABLE 5-2
ASTC IMPACTS

	ASDE-3 (1)				TAGS
	LOCAL CONTROL		GROUND CONTROL		GROUND CONTROL
	Capacity Recovery	Reduced Workload	Controller Capability	Reduced Workload	All Weather Capability
ORD			●		●
JFK		A4R/D4L A22L/D22R	●	A4R/D4L A22L/D22R	(2)
LGA (3)	+22% A22/D13 +11% A22/D31	A13/D13	+30%		(2)
DEN (3)	●		+30%		(2)
ATL	●	●	●	●	●
LAX			●		●
MIA (3)					
SFO			●		(2)

(1) ASDE-3 PROVIDES RELIABILITY, MAINTAINABILITY AND DISPLAY IMPROVEMENTS OVER ASDE-2
(2) TAGS NOT CURRENTLY PLANNED FOR IMPLEMENTATION, BUT MAY HAVE BENEFIT
(3) NOW OPERATES WITHOUT ASDE
● SOME BENEFIT

reduced. For JFK, as well, coordination is reduced for those cases when arrivals on 4L/R or 22L/R have to cross active departure runways. For the ground controller, ASDE-3 offers a better capability than position reports. This capability increase may range up to 30% versus position reports. Reduced workload will be experienced at JFK and ATL, due to a reduced need for coordination with local control, as noted above. Benefits may also be available at LAX, which currently operates with a non-FAA version of ASDE. For DEN and LGA, currently operating without ASDE, there will be significant benefits. For local control at DEN, due to long sighting distances on the north/south runways, ASDE-3 would provide capacity recovery under IFR and certain VFR conditions. For LGA, with arrivals on 22 at minimum visibility, the local controller is unable to observe the intersection, and capacity is lost. Recovery of 11% to 22% capacity is possible with ASDE-3. At LGA, the reliance on position reports for arrivals and departures on 13 would be reduced, as the controller can now directly determine when aircraft have left the runway.

For ground control, an increase in controller peak handling capability of up to 30% versus the capability based upon reliance on position reports may be available. Reduced workload at JFK is achieved due to decreased need for coordination of arrivals crossing active departure runways. MIA does not have an identifiable need for any ASDE at this time.

The main impact of TAGS is to provide the ground controller with a traffic handling capability that does not degrade as the visibility declines. The good visibility capability is maintained, or improved up to 10% according to TSC. This benefit is necessary at those airports where the demand under poor visibility conditions exceeds the currently estimated non-TAGS ground controller capability of 85 operations/hour (2 ground controllers) or 60 operations/hour (1 ground controller). TAGS implementation is currently expected at ORD, ATL and LAX, and possibly later at JFK, LGA, DEN and SFO, if demand during periods of low visibility increases to the limits noted above.

5.2 RNAV Impacts

Area navigation (RNAV) refers to navigation avionics that can provide navigation along a direct course to any destination or to any intermediate way point. The term 2D RNAV refers to an RNAV system which provides navigation in the horizontal plane to a point defined by latitude and longitude or a bearing and distance from a ground station (VOR/DME). The term 3D RNAV adds the third vertical dimention of altitude, and 4D RNAV refers

to a system that includes time as the fourth dimension. The major advantages of RNAV in the terminal area are the return of the navigation task to the pilot, reduction in the number of control instructions issued and the amount of communication between pilot and controller, and frequently, reduction in flight miles when compared with radar vectoring. Area navigation not only affords increased capability to the pilot to control his flight path, thereby reducing the requirement for radar guidance, but also provides the controller with additional tools (e.g., tracks parallel to the base track) for implementing control techniques for the spacing of aircraft.

Several studies of a terminal RNAV environment have been done. For JFK, two extensive simulations were previously performed that evaluate controller workload reductions due to RNAV. For the 2D RNAV case, reductions of 36% in number of control instructions and 23% in radio talk time were observed. For the 3D RNAV simulations, these reductions were 54% and 42%, respectively. For ORD, the FAA estimated that a 30% decrease in arrival control instructions, and a 60% decrease in departure control instructions would occur. Similar benefits may be present at the remainder of the eight airports, although airport specific studies and analyses are not available. Further, these benefits may also be present to a significant degree in environments with only partial RNAV equipage.

There may be some savings from the impact of RNAV in reducing route length. Previous studies estimated savings in fuel (pounds) and time (minutes) from reduced route length and altitude restrictions. Comparisons were made between a 1972 0% RNAV (VOR/Vector) environment and a 1982 100% 3D RNAV design environment. The incremental time savings per aircraft were converted to dollars. The savings reported on in the referenced studies are shown in Table 5-3. They vary from $2.7M annually for DEN to $17.1M annually for JFK. These estimated savings, however, are aggregated from small per aircraft savings and are based on an RNAV route structure optimized to maximize these savings.

5.3 MLS Impacts

The areas of potential MLS impacts were summarized in Table 5-1. In some cases, MLS can be sited where ILS has ground plane siting problems. MLS will provide improved reliability and maintainability compared to ILS, and will have a greatly increased number of assignable frequency channels. This will, in some cases, permit more frequency assignments for major airports, reducing the problems associated with approach guidance outages due to maintenance.

TABLE 5-3
RNAV IMPACTS*

	ANNUAL AIR CARRIER 3D RNAV FUEL AND TIME SAVINGS (1)(5)			2D/3D RNAV WORKLOAD REDUCTION (1)	
	FUEL	TIME	TOTAL	CONTROL INSTRUCTIONS	TALK TIME
ORD	$2.1M	$3.6M	$5.7M	-30% ARRIVAL -66% DEPARTURE	(2)
JFK	$7.4M	$9.7M	$17.1M	-36%/-54% (4)	-23%/-42% (4)
LGA	$3.0M	$7.7M	$10.7M	(2)	(2)
DEN	$1.1M (3)	$1.6M (3)	$2.7M (3)		
ATL	(2)	(2)	(2)		
LAX					
MIA	$1.5M	$2.6M	$4.1M		
SFO	$2.4M	$4.1M	$6.5M		

(1) COMPARISON 0-100% RNAV ENVIRONMENTS EXCEPT JFK 2D SIMULATION (25-100%)

(2) STUDY NOT AVAILABLE, BUT BENEFIT LIKELY

(3) PREVIOUS AIRSPACE GEOMETRY (PRIOR TO 4-POST, PROFILE DESCENT STRUCTURE)

(4) 2D/3D SIMULATIONS

(5) CALCULATED FROM RESULTS OF REFERENCE 21, BASED UPON FUEL AT 3.6¢/LB AND COST OF DELAY TIME AT $9.62/MIN (AIR CARRIERS)

MLS may provide for reduced localizer interference due to reflections from buildings and other ground objects. It may also provide for operational benefits in taxiing departures through reduction in glide slope critical areas. With its ability to define precision curved paths, MLS may provide for both noise relief and reduced airspace conflicts. In addition to those benefits, MLS may provide for the continuation of additional operationally efficient curved or segmented terminal procedures to lower visibility minima than otherwise possible. Finally, in conjunction with other E&D elements (M&S, RNAV), MLS may help provide for an enhanced fail operational capability and more precise turn capability within MLS coverage.

MLS can provide a siting where the lack of an adequate ground plane makes an ILS installation impossible, or of poor quality (resulting in very high approach minima). This is applicable to one existing ILS (MIA 9L) and one desired future installation (ORD 4L). In some geographical areas, there is a requirement for more than the 19 ILS frequencies available. MLS, with 200 frequencies, will eliminate this problem (ORD, LAX, SFO). In addition to providing frequencies for new users at other airports in the reception region, this will enable the major airport to be assigned unique frequencies for each runway end, reducing the maintainance outage impact. Reduced localizer interference will have benefit at those airports with existing interference problems (LAX, MIA 9L and SFO 28L/R), and airports with anticipated future construction in areas likely to cause such interference (DEN 28L, 35L). Reduced glide slope critical areas may lead to operational efficiency in taxiing of aircraft at ORD (A/D runways in CAT II), JFK (A/D on 4L), LGA (A/D on 13, yielding a 9 operations/hour capacity recovery), ATL (8, and in future on 9L), MIA (9L, 30) and SFO (28R in CAT II). In all these cases aircraft taxiing for departure currently must pass through the ILS glide slope critical area, which can be done by only one aircraft at a time, causing operational inefficiencies. Reduced glide slope critical areas would allow this problem to be lessened or eliminated.

The ability to define precise curved paths with MLS serves in some cases to reduce or eliminate airspace conflicts and reduce noise. Major airspace conflicts between JFK and LGA may be resolved with a set of four curved approaches (LGA 13, 22, 31 and JFK 13L/R). This yields a capacity increase (averaged over the total spectrum of yearly operating conditions) of 3% at LGA and average noise reductions of 6% at LGA and 2% at JFK. The provision of precise missed approach guidance may

permit independent IFR and marginal VFR operations on 13L/R at JFK, and help to permit independent IFR operations on 4L/R (3000 foot separation between runways). Precise curved approaches may help to reserve conflicts of ORD 32 parallels with Midway, and to keep parallel approaches at ATL within the TCA. At SFO, the precise departure guidance available from MLS may permit shoreline departures from 28L/R in IFR and poor VFR conditions, with a resultant 30 operations/hour capacity increase in VFR, and noise reductions. Additional curved MLS approaches, generally following existing VFR approaches, may be applied for noise reductions at ORD, ATL, LAX (24L/R Northwest Approach, "Big Tank") and SFO (28L/R Visual). In addition to these applications of MLS for reduced minima for existing VFR approaches, MLS may provide for an additional arrival stream on JFK 22L or 13R when 13L/R or 22L/R, respectively, are being used for arrivals. The JFK 13L/R (Canarsie) approach may also be able to be employed to lower minima.

TABLE 5-4
MLS IMPACTS (1)

	EASE OF SITING	ADDITIONAL FREQUENCIES	REDUCED LOCALIZER INTERFERENCE	REDUCED GLIDE SLOPE CRITICAL AREAS	REDUCED AIRSPACE CONFLICTS	NOISE REDUCTION	ADDITIONAL REDUCED MINIMA WITH PRECISION GUIDANCE
ORD	4L	YES		CAT II A/D RWYS	32 PARALLELS VS MIDWAY	YES	
JFK				ARR 4L/R DEP 4L	13L/R CURVED APPROACHES MISSED APPROACH GUIDANCE ARRIVALS 31L/R, 4L/R	-2% AVERAGE FROM CURVED APPROACHES	ARR 22L/R +MLS ARR 13R ARR 13L/R +MLS ARR 22L ARR 13L/R (CANARSIE)
LGA				ARR 13 (9 OPS/HR CAPACITY RECOVERY)	13, 22, 31 CURVED APPROACHES (3% CAPACITY INCREASE)	-6% AVERAGE FROM CURVED APPROACHES	
DEN			35L 26L	ARR 31L DEP 35R			
ATL				8 (FUTURE 9L)	PARALLEL APPROACHES WITHIN THE TCA	CURVED APPROACHES	
LAX		YES	ALL RW			24L/R NORTHWEST APPROACH	
MIA	30		9L	9L, 30			
SFO		YES	28L/R	28R, CAT II	28L/R IFR SHORELINE DEP (30 OPS/HR CAPACITY INCREASE IN POOR VFR)	ARR 28L/R DEP 28L/R PRECISION APPROACH/ DEPARTURE	

(1) *MLS MAY HELP TO PROVIDE ENHANCED FAIL OPERATIONAL AND PRECISE TURN CAPABILITIES AT MOST OF 8 AIRPORTS*

TABLE 5-5
SUMMARY OF IMPACTS OF ASTC, RNAV, MLS

	ORD	JFK	LGA	DEN	ATL	LAX	MIA	SFO
ASTC - ASDE - RELIABILITY/MAINTAINABILITY/DISPLAY IMPROVEMENTS	◯	◯	*	*	◯	○	*	◯
- LOCAL CONTROLLER - CAPACITY RECOVERY			●	●	◯			
- REDUCED WORKLOAD		◯	◯		○			
- GROUND CONTROLLER - CAPABILITY RECOVERY	◯	◯	●	●	◯	○		◯
- REDUCED WORKLOAD		◯			○			
- TAGS - GROUND CONTROLLER - ALL WEATHER CAPABILITY	●	○	○	○	●	●		○
RNAV - ANNUAL AIR CARRIER TIME & FUEL SAVINGS	○	○	○	○	○	○	○	○
- WORKLOAD REDUCTIONS - REDUCED CONTROL INSTRUCTIONS	●	●	•	•	•	•	•	•
- REDUCED TALK TIME	•	●	•	•	•	•	•	•
MLS - EASE OF SITING	○						◯	
- ADDITIONAL REQUENCIES	◯					●		●
- REDUCED LOCALIZER INTERFERENCE				◯		◯	◯	◯
- REDUCED GLIDE SLOPE CRITICAL AREAS	○	◯	●	◯	◯	○	○	○
- REDUCED AIRSPACE CONFLICTS	○	●	●					●
- NOISE REDUCTION	○	●	●		◯	○		●
- REDUCED MINIMA WITH PRECISION GUIDANCE		●			◯	○		○
- ENHANCED FAIL OPERATIONAL AND PRECISE TURN CAPABILITIES	○	○	○	○	○	○		○

* NO ASDE CURRENTLY

○ POSSIBLE BENEFIT

• PROBABLE BENEFIT BUT NO AIRPORT SPECIFIC STUDY AVAILABLE

◯ DEFINITE BENEFIT

● MAJOR BENEFIT

APPENDIX A

CAPACITY MODEL INPUTS AND RESULTS

The inputs used to compute the capacity and the E&D capacity impact results at the eight airports are given in this appendix. The inputs can be divided into two sets: standard input set obtained from Reference 7 and case specific inputs for particular configurations at the eight airports. These latter are given in the reports on the individual airports.

Tables A-1 through A-4 show the standard inputs used in the capacity computation. These inputs were developed in Reference 7. Table A-1 shows the IFR arrival-arrival separation standard for Today and the four ATC Groups under safe conditions (Green Light), as well as their fallback position under vortex condition. Table A-2 shows the VFR arrival-arrival separation standards. These are only analytic constructs to appropriately represent operations under VFR conditions in the modeling process and, hence, should not be considered regulatory in nature. Table A-3 shows the predicted departure rules for the four ATC groups. The M&S buffer and the Wake Vortex System utilization are shown in Table A-4. Although the basic (IOC) and the advanced M&S system reduce the delivery error, the number of standard deviations (sigmas) to be protected against is increased from 1.65 (0.05 probability of violation) to 2.33 (0.01 probability of violation). This is due to the fact that in the current system the controller is able to anticipate situations in advance and reduce the probability of operational violation. The increase in the number of standard deviations in the M&S buffer assures a suitably low violation probability under a tighter, less flexible automated system. The estimates of Wake Vortex System utilization are based on some preliminary analysis of vortex data.

TABLE A-1
IFR SEPARATION STANDARDS
(NMI)

S - SMALL L - LARGE H - HEAVY

TODAY

TRAIL / LEAD	S	L	H
S	3	3	3
L	4	3	3
H	6	5	4

SAFE CONDITIONS (GREEN LIGHT)

GROUP 1

TRAIL / LEAD	S	L	H
S	3	3	3
L	4	3	3
H	5	4	3

GROUP 2

TRAIL / LEAD	S	L	H
S	3	3	3
L	3.5	3	3
H	5	4	3

GROUP 3

TRAIL / LEAD	S	L	H
S	2.5	2.5	2.5
L	2.9	2.5	2.5
H	4.4	3.5	2.6

GROUP 4

TRAIL / LEAD	S	L	H
S	2	2	2
L	2.4	2	2
H	3.7	3.0	2.3

FALL BACK POSITION UNDER VORTEX CONDITIONS

(TODAY)

TRAIL / LEAD	S	L	H
S	3	3	3
L	4	3	3
H	6	5	4

(GROUP

TRAIL / LEAD	S	L	H
S	3	3	3
L	3.5	3	3
H	5	4	3

TABLE A-2
VFR SEPARATION STANDARDS*
(NMI)

S - SMALL L - LARGE H - HEAVY

TODAY

LEAD \ TRAIL	S	L	H
S	1.9	1.9	1.9
L	2.7	1.9	1.9
H	4.5	3.6	2.7

ALL CONDITIONS

GROUP 1

LEAD \ TRAIL	S	L	H
S	1.9	1.9	1.9
L	2.7	1.9	1.9
H	4.5	3.6	2.7

GROUP 2

LEAD \ TRAIL	S	L	H
S	1.9	1.9	1.9
L	2.7	1.9	1.9
H	4.5	3.6	2.7

SAFE CONDITIONS (GREEN LIGHT)

GROUP 3

LEAD \ TRAIL	S	L	H
S	1.9	1.9	1.9
L	2.5	1.9	1.9
H	4.1	3.2	2.3

GROUP 4

LEAD \ TRAIL	S	L	H
S	1.9	1.9	1.9
L	2.1	1.9	1.9
H	3.4	2.7	2.1

FALL BACK POSITION UNDER VORTEX CONDITIONS

(GROUP 2)

LEAD \ TRAIL	S	L	H
S	1.9	1.9	1.9
L	2.7	1.9	1.9
H	4.5	3.6	2.7

* MODELING CONSTRUCTS ONLY. NOT REGULATORY IN NATURE.

TABLE A-3
DEPARTURE SEPARATIONS*
(SECONDS)

DEPARTURES ON THE SAME RUNWAY**

	GROUP 1	GROUP 2	GROUP 3	GROUP 4
SAFE (GREEN LIGHT) CONDITIONS	60/60/90	60/60/90	60/60/60	60/60/60
FALL BACK - VORTEX CONDITIONS	60/90/120 (TODAY)		60/60/90 (GROUP 2)	

* ALL DEPARTURES ASSUMED TO BE CONDUCTED UNDER IFR RULES

** PRESENTED IN THE FORM:
ANY AIRCRAFT BEHIND SMALL OR LARGE/HEAVY-HEAVY/SMALL OR LARGE BEHIND A HEAVY

TABLE A-4
METERING AND SPACING BUFFERS AND WAKE VORTEX SYSTEM UTILIZATION

	GROUP 1	GROUP 2	GROUP 3	GROUP 4
● METERING AND SPACING				
ONE SIGMA INTER-ARRIVAL ERROR AT THE THE GATE (SECS)	18	11	11	8
NUMBER OF SIGMAS TO BE PROTECTED AGAINST (PROBABILITY OF VIOLATION)	1.65 (5%)	2.33(1%)	2.33 (1%)	2.33(1%)
● WAKE VORTEX SYSTEM UTILIZATION				
SAFE (GREEN LIGHT) CONDITIONS	40%	40%	75%	75%
FALL BACK - VORTEX CONDITIONS	60%	60%	25%	25%

*VORTEX ADVISORY SYSTEM FOR GROUPS 1 AND 2
WAKE VORTEX AVOIDANCE SYSTEM FOR GROUPS 3 AND 4

APPENDIX B

DETAIL OF CAPACITY VALUES

This appendix presents more detailed capacity values to support the presentation in Section 4. All capacity values were calculated based upon 50% arrivals. The terms "Full E&D" and "Fall Back" refer to conditions of reduced or increased separation requiements indicated by VAS/WVAS.

Table B-1 gives the detail of the evaluation of capacity loss in the future resulting from the increasing percentage of heavy aircraft in each airport's traffic mix.

Table B-2 gives the values of the average future capacity gains at each of the eight airports. Included in the Table are partial results for Group 3 provided by AEM-100.

Tables B-3 and B-4 present the detailed capacity values and percent increases, by configuration at each of eight airports, as reported in the seven individual task force reports.

Table B-5 presents the partial Group 3 values prepared by AEM-100.

TABLE B-1
CAPACITY LOSS DUE TO INCREASING NUMBER OF HEAVY AIRCRAFT

AIRPORT	PERCENT HEAVY AIRCRAFT IN MIX			AVERAGE PERCENTAGE CAPACITY LOSS TODAY VS GROUP 4 TIME FRAME DUE TO INCREASING NUMBERS OF HEAVY AIRCRAFT	
	TODAY	GROUP 2 TIME FRAME	GROUP 4 TIME FRAME	VFR	IFR
ORD	13	25	48	7	5
JFK	62	67	72	1	0
LGA	3	9	15	5	3
DEN	9/13*	15/22*	25/35*	17	4
ATL	13	33	46	11	10
LAX	31	50	70	9	6
MIA	25	36	48	4	4
SFO	18/20*	24	39	3	2

*VFR/IFR

TABLE B-2
AVERAGE PERCENTAGE CAPACITY INCREASE*

	GROUP 2		GROUP 3**		GROUP 4	
	Full	Fall Back	Full	Fall Back	Full	Fall Back
VFR						
ORD	4	1			21	10
JFK	10	1			20	12
LGA	2	2			9	6
DEN	2	2			22	10
ATL	5	0			18	10
LAX	4	3			13	11
MIA	5	3	9	7	12	8
SFO	5	2	7		9	4
IFR						
ORD	5	2	13		36	17
JFK	15	3	23		38	22
LGA	3	2	2		14	8
DEN	9	3	15		24	17
ATL	9	4	13		18	10
LAX	15	3	31		51	27
MIA	1	0	5	1	6	2
SFO	11	2	19		34	21

*COMPARED TO TODAY'S ATC SYSTEM WITH FUTURE AIRCRAFT FLEET MIX.
**GROUP 3 VALUES WERE PART OF TASK FORCE EFFORT ONLY AT MIA AND AT SFO. PARTIAL GROUP 3 VALUES WERE SUPPLIED BY THE FAA FOR OTHER AIRPORTS FOR SINGLE CONFIGURATIONS (SEE TABLE B-5).

TABLE B-3
VFR CAPACITY VALUES

			CAPACITY*							PERCENT INCREASE**			
				GROUP 2			GROUP 4			GROUP 2		GROUP 4	
AIRPORT	ARRIVAL RUNWAYS	DEPARTURE RUNWAYS	TODAY	FULL E&D	FALL BACK	MIX IMPACT	FULL E&D	FALL BACK	MIX IMPACT	FULL E&D	FALL BACK	FULL E&D	FALL BACK
ORD	9L, 14L	4L/R	142	145	139	139	157	144	133	4	0	18	8
	27L/R	32L/R	152	154	154	150	169	155	141	3	3	20	10
	14L/R, 9R	4L/R	180	185	176	175	203	184	163	6	0	25	13
JFK	22L/R	22R	77	87	77	76	97	91	76	14	1	28	20
	31L/R	31L	73	77	74	73	82	77	73	5	1	12	5
LGA	22	13	78	77	77	75	85	80	73	3	3	16	10
	4	4	53	52	52	52	52	52	51	0	0	2	2
DEN	26L/R	35L/R	128	121	121	119	128	114	103	2	2	24	11
	17L/R	8L/R	121	116	116	113	124	112	103	3	3	20	9
ATL	8, 9R	8, 9L	144	140	133	133	151	141	128	5	0	18	10
	26, 27L	26, 27R	144	140	133	133	152	141	128	5	0	19	10
LAX	24L/R, 25L/R	24L/R, 25L/R	155	151	150	146	160	156	141	4	3	13	11
MIA	9R/L, 12	9R/L, 12	100	100	98	98	104	102	96	2	0	8	6
	27L, 30	27R/L	116	122	120	114	127	121	110	7	5	15	10
SFO	28L/R	1L/R	109	111	108	106	[illegible]	110	[illegible]	5		[illegible]	[illegible]

*SOURCE: TASK FORCE REPORTS (MTR-7350, VOLS. I-VII)

**COMPARED TO VALUE FOR TODAY'S SYSTEM WITH FUTURE AIRCRAFT MIX ("MIX IMPACT")

TABLE B-4
IFR CAPACITY VALUES

			CAPACITY*							PERCENT INCREASE**			
				GROUP 2			GROUP 4			GROUP 2		GROUP 4	
AIRPORT	ARRIVAL RUNWAYS	DEPARTURE RUNWAYS	TODAY	FULL E&D	FALL BACK	MIX IMPACT	FULL E&D	FALL BACK	MIX IMPACT	FULL E&D	FALL BACK	FULL E&D	FALL BACK
ORD	14L/R	9L/R	114	115	115	114	129	121	108	1	1	20	12
	14L/R	9L, 27L	114	125	117	114	136	128	108	10	3	26	19
	27L/R	32L/R	114	125	117	114	164	132	108	10	3	52	22
JFK	22L/R	22R	57	64	58	57	77	69	57	12	2	35	21
	31R	31L	53	63	55	53	75	65	53	19	4	40	23
LGA	22	13	60	62	61	59	73	66	57	5	3	28	16
	4	4	48	48	48	48	48	47	47	0	0	2	0
DEN	35R	35L	62	66	63	61	71	69	59	8	3	20	17
	26L	35L/R	62	67	63	61	77	71	60	10	3	28	18
ATL	8, 9R	8, 9L	114	116	110	106	122	113	103	9	4	18	10
	26, 27L	26, 27R	114	115	110	106	122	113	103	8	4	18	10
LAX	24R, 25L	24L, 25R	108	120	107	104	154	130	102	15	3	51	27
MIA	9R/L	9R/L	90	89	88	88	91	88	86	1	0	6	2
SFO	28R	1L/R	54	60	55	54	71	64	53	11	2	34	21

*SOURCE: TASK FORCE REPORTS (MTR-7350, VOLS. I-VII).
**COMPARED TO VALUE FOR TODAY'S SYSTEM WITH FUTURE MIX ("MIX IMPACT").

TABLE B-5
SUPPLEMENTAL GROUP 3 CAPACITY VALUES

AIRPORT	ARRIVAL RUNWAYS	DEPARTURE RUNWAYS	TODAY**	CAPACITY			PERCENT INCREASE***	
						GROUP 4** MIX IMPACT	GROUP 3	
				FULL E&D	FALLBACK		FULL E&D	FALLBACK
IFR								
ORD	14L/R	9L/R	114	122	--	108	13	--
JFK	31R	31L	53	68	--	53	28	--
LGA	4	4	48	48	--	47	2	--
DEN	35R	35L	62	68	--	59	15	--
ATL	9R, 8	8, 9L	114	119 (est.)	--	103	13	--
LAX	24R, 25L	24L, 25R	108	134	--	102	31	--
MIA	9R/L	9R/L	90	90	87	86	5	1
SFO	28R/L	1R/L	54	64	--	54	19	--
VFR								
MIA	9R/L, 12	9R/L, 12	100	102	99	96	6	3
	27L, 30	27R/L	116	123	121	110	12	10
SFO	28L/R	1L/R	109	113	--	106	7	--

*SOURCE: AEM-100.
**SOURCE: TASK FORCE REPORTS (MTR-7350, VOLS. I-VII).
***COMPARED TO VALUE FOR TODAY'S SYSTEM WITH GROUP 4 MIX ("MIX IMPACT").

APPENDIX C

IMPACT OF E&D ELEMENTS ON BASIC RUNWAY CONFIGURATIONS

The E&D elements affecting runway capacity have a greater impact on some runway use configurations than others. This may be further illustrated with the aid of Table C-1 and Figure C-1. These show the percentage capacity gain in various types of runway use for the Group 4 time frame versus today. They are based on parameter values generally used by the Task Forces, with the exception of arrival runway occupancy times. These have been set at values representative of the presence and use of high speed exits. The range in each estimate reflects the variation in the percentage of heavy aircraft in the fleet mix at the eight airports.

The capacity gains represented reflect a runway and terminal system with no major internal constraints apart from ATC system performance. The arrival/departure runway configuration shows the least benefit, due to the fact that the basic timing between aircraft can not be further reduced from today. The gain that occurs is due to [illegible] performance, and some reductions in spacings for heavy aircraft. Two runways in a crossing configuration may vary in actual operational appearance from the equivalent of a single arrival/departure runway to a dual-lane, depending on the geometry of the intersection. For a case between these extremes, the potential gain is around 20-35%. The dual-lane is the best mixed operations configuration, and offers IFR gains up to 60%. For arrivals only, VFR gains are less than IFR, due to the fact that current spacing criteria more closely reflect feasible spacings. Finally, the relaxation of departure-departure spacing requirements may yield a large impact for a departure only runway with a large percentage of heavy aircraft.

These illustrations serve to underline the conclusions in the text of this report as to the most effective application of E&D products.

TABLE C-1
PERCENTAGE CAPACITY GAIN IN FUTURE FOR VARIOUS RUNWAY USE CONFIGURATIONS*

	VFR	IFR
ARRIVAL/DEPARTURE	13-16	12-18
CROSSING**	17-39	17-37
DUAL-LANE	17-39	39-61
ARRIVAL ONLY	17-30	52-61
DEPARTURE ONLY	5-44	5-44

*BASED UPON MODEL OF REFERENCE 8, WITH ASSUMED OPTIMUM RUNWAY OCCUPANCY TIMES, AND EIGHT AIRPORT REPRESENTATIVE AIRCRAFT MIXES.

**A "SHORT/LONG" CROSSING CONFIGURATION WAS MODELED - OTHER CROSSING CONFIGURATIONS WILL HAVE DIFFERENT RESULTS.

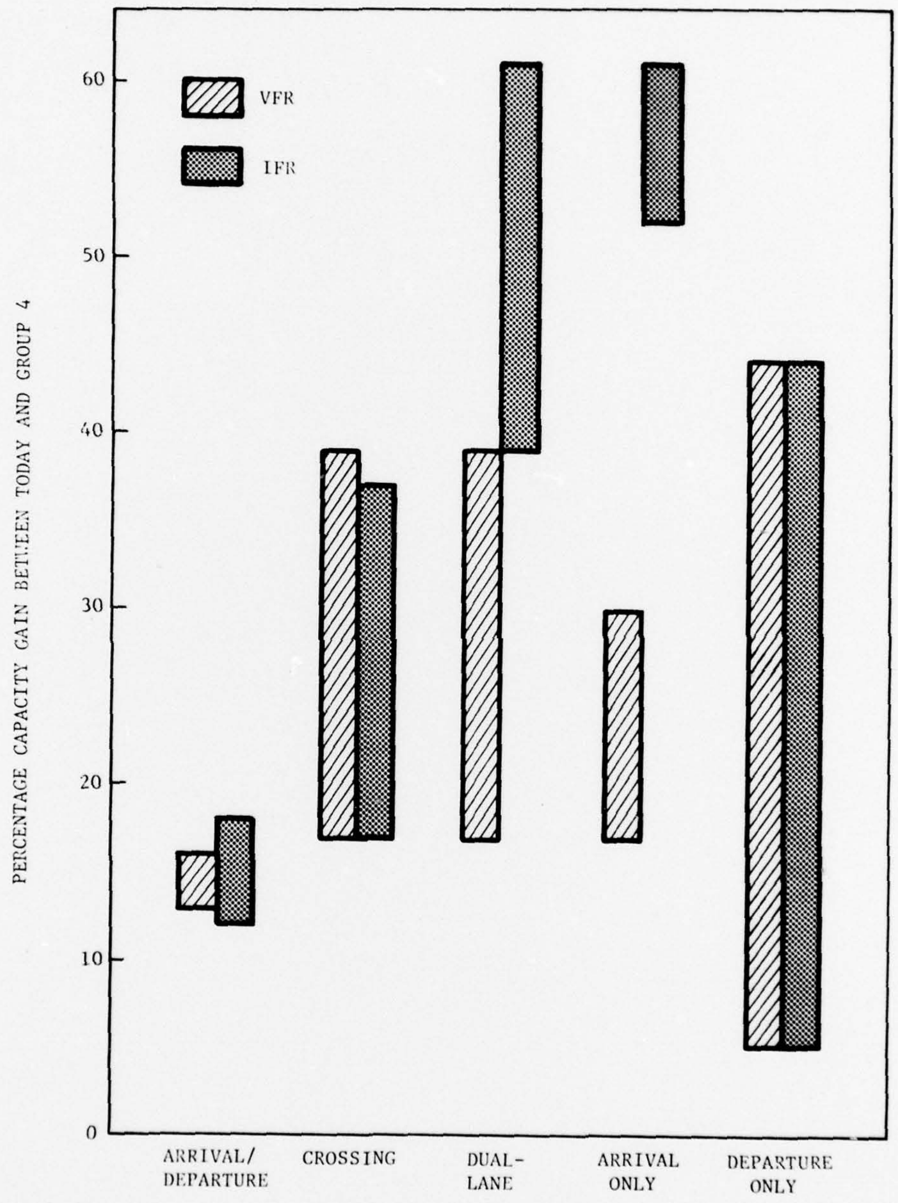

FIGURE C-1
PERCENTAGE CAPACITY GAIN IN FUTURE FOR VARIOUS RUNWAY USE CONFIGURATIONS

APPENDIX D

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APPENDIX E

AIRPORT LAYOUT SKETCHES

Figure E-1 provides, for reference, sketches of the runway layouts at the eight airports. It may be pulled out for reference as the report is read.

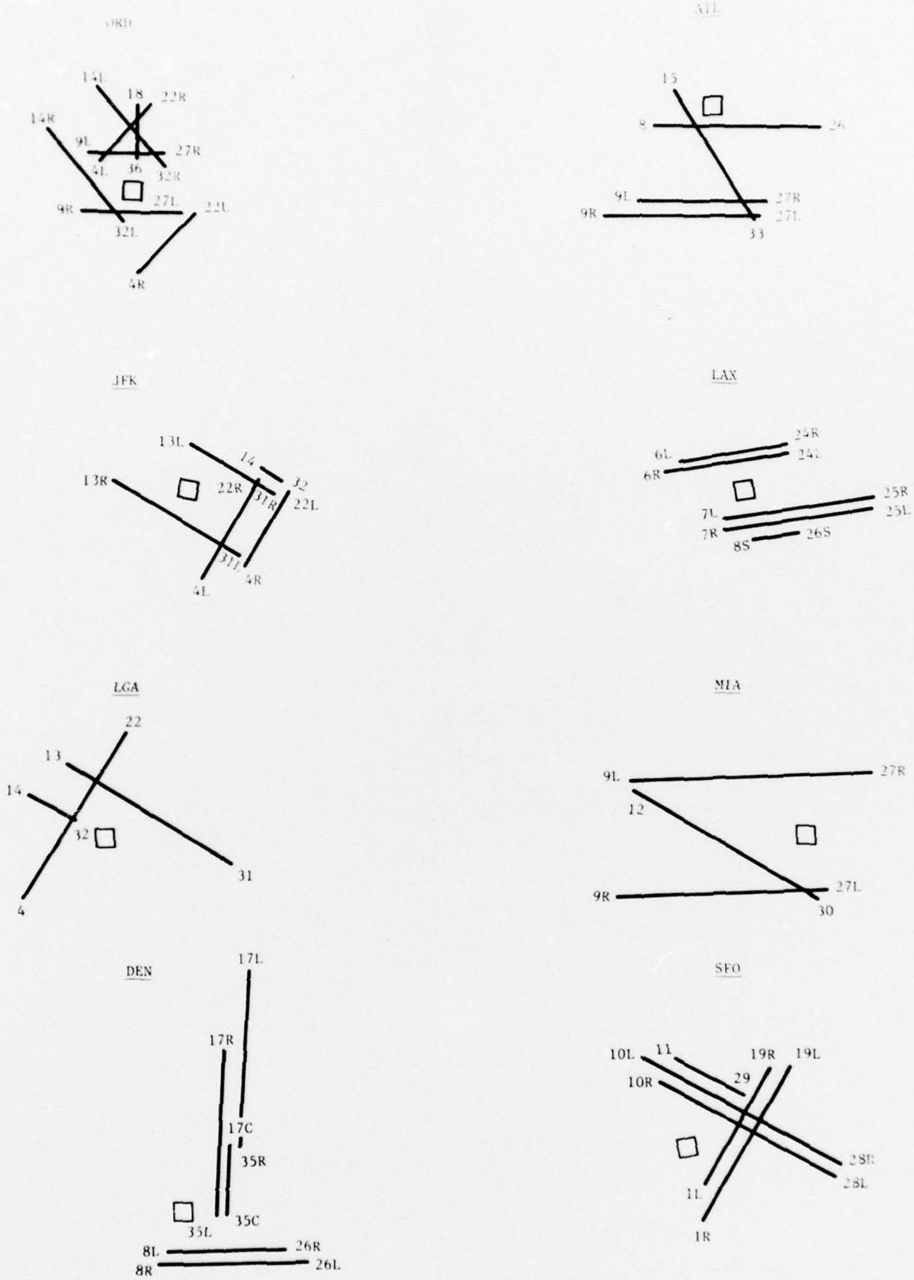

FIGURE E-1
EIGHT AIRPORT RUNWAY LAYOUT SKETCHES